MINISTRY OF FINANCE, EGYPT.

SURVEY DEPARTMENT.

THE GEOGRAPHY AND GEOLOGY OF WEST-CENTRAL SINAI

BY

JOHN BALL, Ph.D., D.Sc.,

F.G.S., A.R.S.M., M.INST.C.E.

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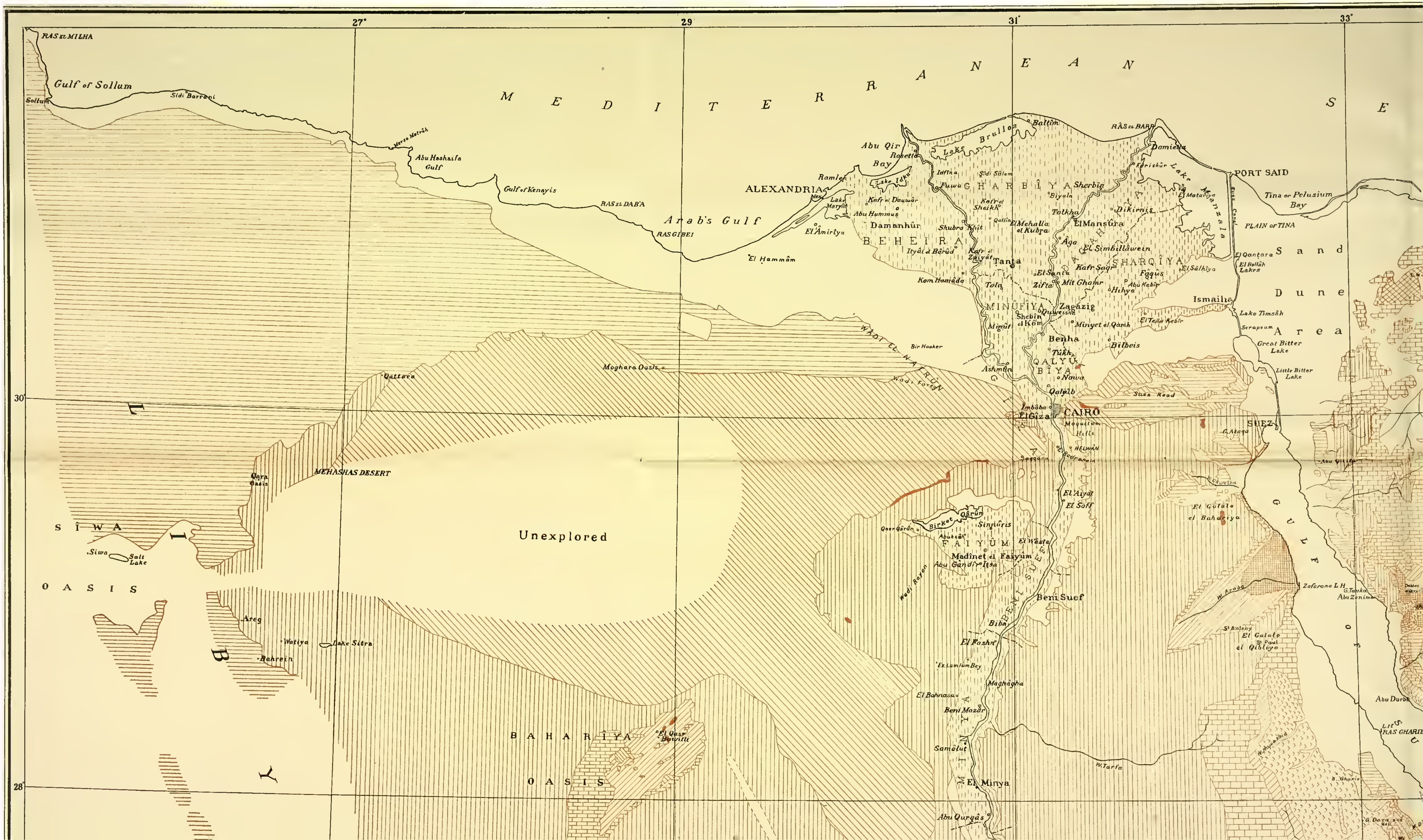
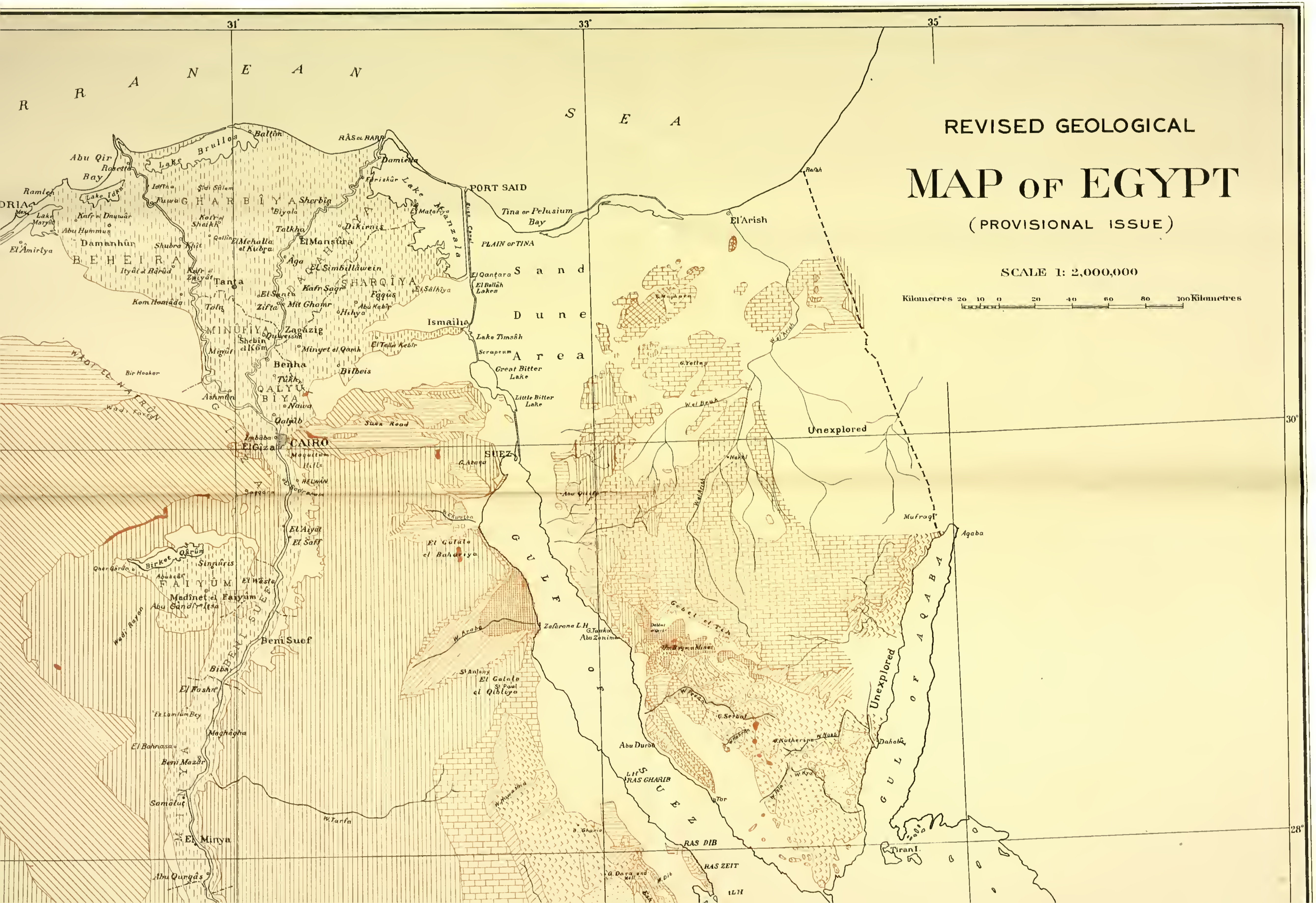
W. F. Hume-Geology of Egypt.




REVISED GEOLOGICAL
MAP OF EGYPT
(PROVISIONAL ISSUE)
SCALE 1: 2,000,000
Kilometres 20 10 0 20 40 60 80 100 Kilometres
MEDITERRANEAN SEA
CAIRO
PORT SAID
SUEZ
Sand Dune Area
Unexplored
GULF OF SUEZ
GULF OF AQABA
FAIYUM
Beni Suef
El Minya
El'Arish
Ismailia
Tanta
Zagazig
Benha
Damietta
Aqaba
Tiran I.
RAS GHARIB
RAS DIB
RAS ZEIT

OASIS
FARAFRA
Ain Iddeila or El Daila
Bir Murr
Qasr Farafra
OASIS
Sand
Dunes
Unexplored
Abu Moharik Sand Dunes
DAKHLA
Qasr Dakhl
Mut
OASIS
KHARGA
Abu Moharik
Kharga
OASIS
Dakhakhin
Beris
Dush
Rogenfeld
Bir Murr
El Minya
Abu Qurqas
Mallawi
Dairut
Manfalut
Abnub
Asyut
Abu Tig
El Badari
Tahta
Akhmim
Sohag
Girga
El Balyana
Dishna
Qena
Nag' Hammadi
Qift
Qus
Karnak
Luxor
Armant
Isna
Sebaia
Idfu
Kom Ombo
El Khattara
Aswan
Philae
Dabod
Kalabsha
Dandur Temple
El Dakka
Kurkur Oasis
Dunqul Oasis
Unexplored
MA'AZA
LIMESTONE
PLATEAU
RIVER
NILE
Wadi Qena
LIBYAN DESERT
REFERENCE
Nile Alluvium
Pliocene, Pleistocene and Recent
Miocene
Oligocene
Eocene
Cretaceous
Nubian Sandstone
28°
26°
24°

El Minya
Abu Qurqas
Mallawi
Dairut
Manfalut
Abnub
Asyut
Abu Tig
El Badari
Tahta
Akhmim
Sohag
Girga
El Balyana
Dishna
Nag' Hammadi
Qena
Qift
Qus
Karnak
Luxor
Tombs of the Kings
Armant
Isna
Sebaia
Idfu
Kom Ombo
El Khattara
Aswan
Philae
Dabod
Kalabsha
Dandur Temple
El Dakka
M A ' A Z A
L I M E S T O N E
P L A T E A U
RIVER
NILE
Wadi Qena
K H A R G A
O A S I S
Kharga
Abu Moharik
Dakhakhin
Baris
Dush
Moharik Sand Dunes
xplored
Kurkur Oasis
Dunqul Oasis
Bir Murr
Unexplored
Unexplored
RAS DIB
RAS ZEIT
Tiran I.
RAS MOHAMMED
Gaysum Is
Jubal Is
RAS GEMSA
Shadwan I.
Abu Shaar
Hurghada
Gifatin Is
G. Abu Dukhan
RAS ABU SOMA
Safaga
Safaga I.
W. Semna
The Brothers L.H.
Qoseir
Bir el Inglis
W. Hamamat
Bir el Sid
Lageita Wells
W. Karim
Mersa Imbarak
Um Rus Mine
Sigdit Well
Bir Abu Dabab
Bir Beza
W. Shagab
W. Mia
Bir Kanais
W. Abad
Bir Abad
Bir Dungash
Mersa Tundeba
Dædalus Lighthouse
W. Shait
W. Beza
Bir Samut
Bir Um Gubur
Bir Masur
W. Natash
G. Zabara
Wadi Gemal I.
Sherm Sheikh
Gulhan Is
W. Kharit
Bir Abu Hamamid
Bir Shadli
W. Kharit
Berenice
RAS BENAS
Foul Bay
St John's I.
Tropic of Cancer
Wadi Khoda
Bir Abraq
Bir Abu Saafa
Bir Um Rait
G. Hamret Feg
Bir Shalatein
R E D
S E A
28°
26°
24°

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KHARGA
OASIS
Kharga
Abu Moharik
Dakhakhin
Bir Murr
El Sheb
Qus
Lagerta Wells
Karnak
Luxor
Armant
Isna
Sebaia
Idfu
NILE
Kom Ombo
El Khattara
Aswan
Philae
Dabod
Kalabsha
Dendur Temple
El Dakka
El Derr
Korosko
Temples of Abu Simbel
Wadi Halfa
Kurkur Oasis
Dunqul Oasis
Unexplored
Unexplored
Unexplored
Mersa Imbarak
Sigait Well
Mersa Tundeba
Daedalus Lighthouse
Wadi Gemal I.
Sherm Sheikh
Gulhan Is
Berenice
RAS BENAS
Foul Bay
St John's I.
Tropic of Cancer
Bir Abraq
Bir Shalatein
G. Homret Teg
Mersa Shab
Wadi Shab
Bir Um Garaiat (Gold Mine)
Bir Ungat
Bir Jugub
G. Um Rasein
Halaib
RAS QURET ISA
RAS HADARBA
G. Elba
RED SEA
Political Boundary
SUDAN
24°
22°
31°
33°
35°

GEOGRAPHY
AND
GEOLOGY
OF
WEST CENTRAL
SINAI

—

BALL.

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PREFACE.

This book contains the results of the survey, in 1913–1914, of a portion of the Sinai Peninsula which has recently become of some importance by reason of the commercial exploitation of the deposits of manganese and iron ores which it contains. The district forms part of a vast area reconnoitred in 1898–1899 by the late Mr. Thomas Barron, of the Geological Survey, who discovered the ore deposits and thus laid the foundation for the mineral industry now springing up in Sinai. Mr. Barron's reconnaissance was conducted at such a rapid rate (he covered 3,500 square miles in the course of five and a half months) that the accurate fixation of positions and detailed mapping were out of the question; but a comparison of the geological chapters of the present work with his "Topography and Geology of Western Sinai," published after his lamented death in 1907, will show how accurately he had grasped the general geological structure of the region, and his reconnaissance notes have been of great utility in conducting the more detailed survey.

In Chapter I is given a general description of the district, adapted for the general reader who does not desire to go into much detail concerning it. Chapter II contains an account of the survey operations on which the present work is founded, and comparisons of the resulting positions with those found in previous surveys. Some of the survey methods employed are new or little known, but have been found specially adapted to mountainous desert conditions, and these are discussed somewhat fully, in view of their being likely to find useful application elsewhere; in particular I would cite the employment of two theodolites and short bases in the topographical mapping, which constitutes a method presenting many advantages over ordinary tacheometry in very rugged country, and enables accurate mapping to be carried on at a much faster rate than is practicable by any of the ordinary text-book methods. Chapters III and IV contain a systematic description of the drainage lines and hill features. In Chapter V, I have collected together the notes made during reconnaissance journeys in the country between Abu Zenima and Suez.

Chapter VI deals with the stratigraphical geology of the region, while in Chapter VII the physical geology, including the formation of ore deposits and oil, is considered.

The principal features of the geographical portion of the work are the precise determination of positions by trigonometric connexion with Egypt, and the detailed mapping of a typical portion of one of the most rugged tracts of the earth's surface. In the geological chapters the careful demarcation of the limits of the different divisions of the Carboniferous, the proof of the intrusive nature of the basalts, and the investigations regarding the origin of the manganese ores and oils, are the chief advances.

The maps illustrating the work are direct photographic reproductions of the field sheets. The plates showing scenic features are from photographs taken during the work. In the geological chapters, besides the illustrative sections copied from my note book, I have added pen-and-ink illustrations of the most typical fossils, drawn by myself from actual specimens, because many of them are species of which figures are only to be found in scattered palæontological papers, and a few are new to science.

The chief gap in our knowledge of this region is now the composition and structure of the Pre-Carboniferous igneous and metamorphic rocks; to have attempted the unravelling of the fundamental complex in the time which could be devoted to the work would have meant a less complete study of the fossiliferous formations in which the economic products occur, and I was therefore reluctantly compelled to leave the task for a future worker in the field.

My cordial thanks are due to Mr. R. Bullen Newton, of the British Museum, who has kindly named the Carboniferous mollusca, and to M. R. Fourtau, on whom I have relied for the determination of the Mesozoic and Tertiary fossils. I am also greatly indebted to Mr. F. S. Richards, M.A., who accompanied me in the spring of 1913 and aided me in the astronomical computations and in the primary triangulation: also to Mr. O. H. Little, M.A., who was with me throughout the season 1913–1914 and rendered much useful help in both the topographical and the geological surveying.

JOHN BALL.

CORRIGENDA.

Page 45, line 5 from bottom, *for* "chartered" *read* "charted."

„ 59 „ 23 „ top, *for* "$d = h \tan \theta$" *read* "$d = h / \tan \theta$."

„ 84 „ 6 „ bottom, *for* "tract" *read* "track."

„ 99, lines 1, 5, 15, and 18 from top, *for* "Baba" *read* "Baʿla."

„ 111, line 4 from bottom, *for* "basalt" *read* "basal."

„ 115 „ 10 „ „ *for* "Where" *read* "When."

„ 124 „ 7 „ „ *for* "of" *read* "or."

„ 124 „ 3 „ „ *for* "microscopic" *read* "macroscopic."

„ 150 „ 13 „ „ *for* "horizon" *read* "horizons."

„ 164 „ 10 „ „ *for* "Tilaʿgebir" *read* "Tilaʿgabir."

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CHAPTER II.

CHAPTER III.

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LIST OF ILLUSTRATIONS IN THE TEXT.

GEOGRAPHY AND GEOLOGY OF WEST-CENTRAL SINAI.

CHAPTER I.

GENERAL DESCRIPTION OF THE DISTRICT.

Extent.

The position of the district with which this book is mainly concerned, *i.e.* the tract mapped in detail, is indicated by the shaded area in the sketch map in Figure 1. It extends from the high escarpment of Gebel el Tih, in north latitude 29° 15′, across the sandy plain called Debbet el Qeri and the mountainous area drained by the Wadi Baba and its tributaries, southward to the parallel of 28° 56′ 20″. Its western limit, formed by the meridian of 33° 9′ 35″ east of Greenwich, passes along the western flanks of Gebel Abu 'Edeimat, along the Matulla range, and cuts the sea coast a little south of the port of Abu Zenima; while its eastern boundary, the meridian of 33° 27′ 30″, cuts across the Gebel el Tih and passes a little east of the temple of Serabit el Khâdim. The total area covered by the detail map (Plate I) is approximately 970 square kilometres, or 380 square miles.

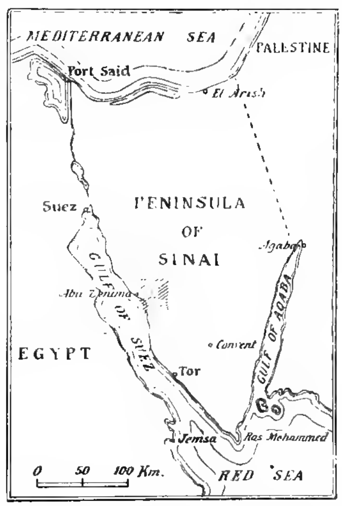

FIG. 1.—Sketch map of Sinai; the shaded area shows the position of the district surveyed in detail.

Relief.

The Peninsula of Sinai is one of the most rugged tracts on the earth's surface, and the small portion of it with which we are now concerned, though it does not include the highest mountains, is a fair sample of the whole peninsula, consisting of highly dissected table-lands and assemblages of rugged granitic peaks, with occasional

more open areas. Owing to its complicated geological structure, the district presents a great variety of geographical forms. The same agents of denudation and sculpture, acting in areas characterized by rocks differing in hardness and disposition, have produced corresponding variations of surface relief. To a certain extent, of course, the rocks which are specially characteristic of one area pass over into adjoining ones, and it is thus not possible always to draw hard-and-fast lines of demarcation of the different morphological types. But it is easy to recognize five areas, in each of which a particular type of surface sculpture is predominant; these are :—

1. **Gebel el Tih,** an intensely dissected limestone plateau, which, rising to heights of nearly 1,200 metres above sea,* forms the extreme north portion of the district, with bold sinuous scarps over 500 metres high facing to the south. Gebel Abu 'Edeimat (800 metres) forms a semi-detached part of Gebel el Tih, while Gebels Sarbut el Gamal (642 metres) and Musaba Salâma (583 metres) may be considered as outlying portions of the same great mass.

2. **The Debbet el Qeri** ("Debbet el Ramla" of existing maps†), a sandy plain at an average height of about 500 metres above sea, with some low hills, footing the scarp of Gebel el Tih.

3. **The White Hills near the coast north of latitude 29°.**—These hills are a series of small ranges, mostly of dazzling white chalk; the principal range, which is called Gebel Matulla, attains an altitude of over 400 metres. A smaller tract of the same class of country extends round the mouth of Wadi Baba, further south.

4. **The highly eroded mountainous tract** which forms almost the entire southern half of the district. This rugged tract, whose principal summits include Gebels Nukhul (674 metres), Samrâ (695 metres), Um Bogma (731 metres), Moneiga (949 metres), Abu Treifia (1,024 metres), Farsh el Azraq (790 metres), Um Riglein (1,037 metres), Sarabit el Khâdim (1,096 metres), and Adeidia (1,044 metres), consists of a foundation of ancient granitic rocks, with local cappings of sedimentary strata and sheets of basalt, the whole being cut up in a most intricate manner by deep canyon-like wadis, whose steep side-walls are often several hundred metres in height.

* This refers only to the portion considered in the present work; further east the plateau rises to over 1,600 metres.

† For reasons for changing this name, *see* page 87.

5. **The coast plain of Elwa Baba,** sometimes called the plain of El Markhâ. This is a gravelly tract in the extreme south-west corner of the district, shelving gradually down from the feet of the hills to the sea coast.

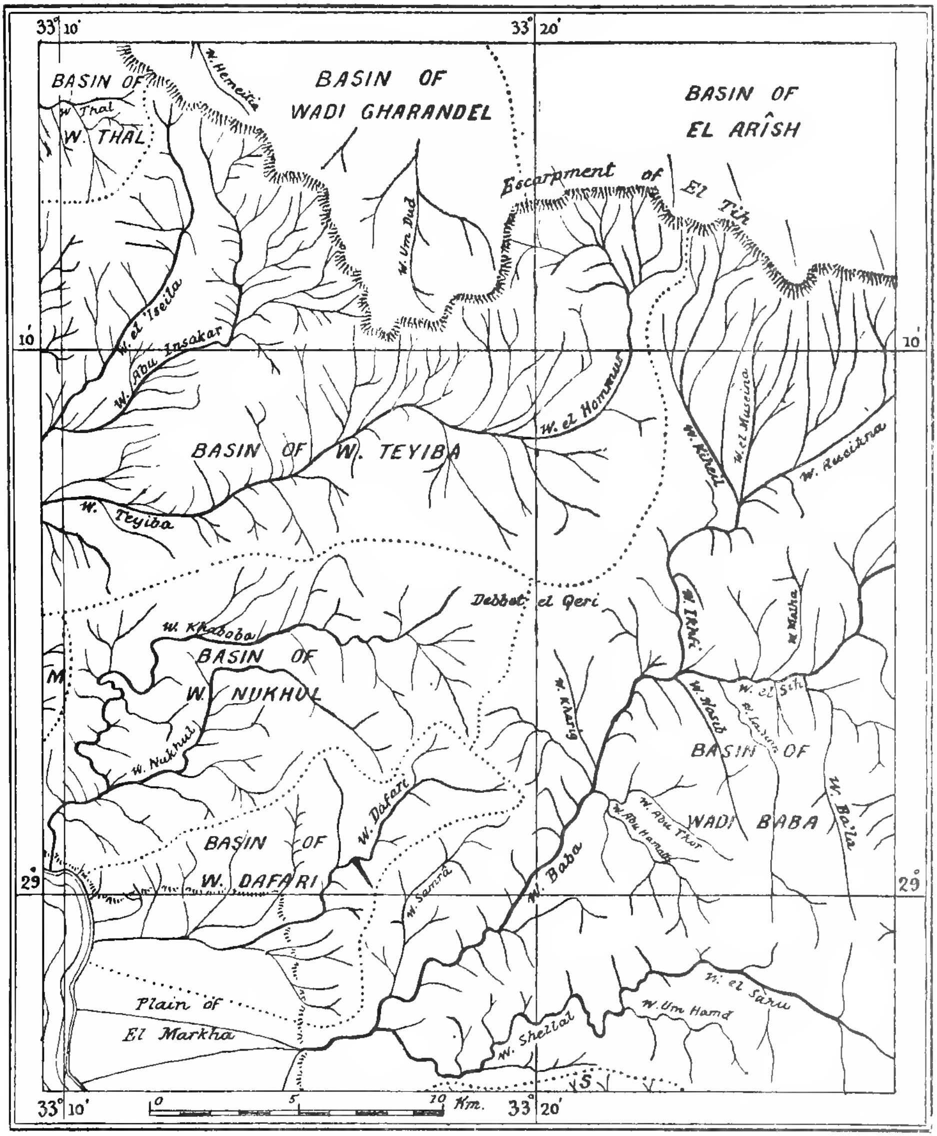

FIG. 2.—Sketch map showing drainage system. Scale 1 : 250,000. The dotted lines indicate the limits of the various basins. *M.* basin of Wadi Matulla; *S.* basin of Wadi Sidri.

Hydrography.

With the exception of a small tract to the north of the Tih escarpment, which drains to the Mediterranean at El 'Arîsh, the whole

drainage from this part of Sinai enters the Gulf of Suez. The main drainage basins are shown on the sketch map in Figure 2. Of the wadis draining in a northerly direction from the Tih escarpment, only the heads have been surveyed, and the precise position of the dividing line between the basins of Wadi el 'Arîsh (Mediterranean) and Wadi Gharandel (Gulf of Suez) is not very certain; the wadis were not followed down far enough to be sure as to their place of outflow. South of the escarpment, however, all the drainage lines have been mapped in detail. The main trunk wadis, taken in order from north to south, are: Wadi Thal, entering the Gulf of Suez in latitude 29° 8′, among the coastal hills called Gebel Hammam Faraûn; Wadi Teyiba, draining most of the plain of Debbet el Qeri and reaching the gulf near Ras Abu Zenima in latitude 29° 3′; Wadi Nukhul, with its great tributary Wadi Khaboba, draining the Gebel Nukhul District and entering the gulf a little to the north of Elwa el Markhâ; Wadi Dafari, with Wadi Beidâ, draining the mountainous tract round Gebel Samrâ; Wadi Baba, with its great tributary the Wadi Shellal, draining almost the entire south part of the district by an extremely complicated system and ultimately reaching the sea in a fan-like manner over the plain called Elwa Baba. Of the Wadi Gharandel, north of Wadi Thal, and of Wadi Sidri, the next great drainage line to the south of Baba, only the heads of a few tributaries come within the limits of the map.

Besides these main drainages, there are a number of minor wadis which drain small tracts and reach the gulf independently north of the plain of Elwa el Markhâ; the chief of these minor wadis is the Wadi Matulla.

For the traveller, it is important to note that very few of the wadis can be traversed along their entire course, owing to the frequency with which their rocky beds contain precipitous drops over ledges of hard rock. Wadi Teyiba and Wadi Nukhul may be ascended from their mouths up to near their heads, but most of the other drainage lines present formidable steps somewhere or other in their course, and are consequently avoided as main roads by the Arabs. Wadi Baba is frequently impassable by reason of running water, while till lately its greatest tributary, the Wadi Shellal, was obstructed by a precipitous drop in its rocky floor just below the Wadi Sahu; but this obstruction has now been destroyed by blasting, to form a road up to the mines of Um Bogma.

Climate.

The climate of this part of Sinai, as of the peninsula as a whole, is temperate and dry and very healthy. But wind has far more to do with personal comfort than mere temperature, and corresponding to the great range of altitudes and exposure, the conditions vary considerably in the different parts of the district, even in the same season of the year. On the top of Gebel el Tih and any of the higher mountains, very cold piercing winds prevail in winter, and the traveller needs his warmest clothing.* At lower altitudes, especially where sheltered in the deep cut wadis, these winter winds are less severe. On the tracts near the coast, warm wet mists are apt to fill the air for days at a time, even in winter, and the lack of evaporation from the skin makes one very uncomfortable when climbing under these conditions. In summer, the Tih plateau is cooled by the prevalent north breezes, while the sheltered wadis, where not shaded from the sun, are oven-like in temperature. The sandy plain of Debbet el Qeri is nearly always hot, unless there is a strong northerly wind. Rain occasionally falls, but the average yearly amount is probably under an inch ; and snow occurs in some years on the higher mountains. How clear the air may be in the district is illustrated by the fact that many triangulation sights have been taken over distances exceeding 100 kilometres, the longest being one of 166 kilometres.

Animal and Plant Life.

Of animals suitable for food, ibex and hares are the only wild creatures abounding in the district, and even they are comparatively scarce. The natives are excellent hunters, and judging from my experience of two rather dry years, by employing a hunter continuously one may expect to get a couple of ibex in a month, and three or four hares, in the Gebel el Tih District. Further south, about half the number. A hunter costs eight piastres a day, so that it is rather a dear way of getting meat.

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* During the month I spent on the top of El Tih in January and February 1913, I found a small petroleum stove of great service, especially when working out the trigonometrical and astronomical calculations in camp in the evenings; without it my hands would have been too cold to hold a pencil.

Of other wild creatures, the coney is the most interesting. I kept one for over a month, and he was moderately tame being let loose about the tent and loving to lie near the oil stove in winter. The food he liked best was acacia leaves, but hardly anything in the vegetable food line came amiss to him, and nuts were much enjoyed. I lost him by having to leave him in the care of my camel men while up a mountain, and I believe he must have perished from cold, though I gave careful instructions to keep him warm.

Birds are not very numerous, but ravens are frequently seen, often perched on camel-back picking out vermin. Wagtails are the commonest of small birds.

Lizards are common, snakes less so. I only had one instance of snake-bite brought to my notice during my two seasons' work, and the man, though he was seriously ill, recovered under treatment with potassium permanganate and a libation of whisky. Flies were a nuisance in summer, especially near mining camps; but they are totally absent from the higher desert in winter.

As to vegetation, Sinai is by no means a desert in the sense of being quite devoid of green stuff. Palm groves are plentiful in some of the valleys, especially Wadi Baba, while acacia trees abound along many of the great drainage lines, and the Debbet el Qeri is sufficiently clothed with shrub vegetation to afford tolerable grazing for goats and camels. The indigo plant was found growing wild in a little gully near the mouth of Wadi Shellal.

Water Supplies.

The sources of drinkable water in this part of Sinai are not very numerous, nor as a rule very easy of access. A list of all the sources noted as of any importance is given in the table below, where the characters of the waters are given for the dry years of 1913–1914. The most important of the wells is Bir Nasib, which yields abundance of excellent water, very easy of access; and this well formed the main source from which my supplies were derived during the survey. A view of Bir Nasib is shown on Plate II. Running water is found among the palm groves in some of the wadis, such as Baba and Teyiba, but is unfortunately usually too brackish to be drinkable except by camels.

Bir Nasib, from the south.

Ruins of Temple, Sarabit el Khâdim.

List of Water Sources.

Name.	Lat. N. ° ′ ″	Long. E. ° ′ ″	Alt. above Sea. Metres.	Remarks.
Bir Thal	29 14 25	33 9 38	345	Pool in upper part of Wadi Thal, among palms and rocks. Water good and supply perennial, the pool filling as fast as emptied.
Bir Qattar	29 14 25	33 10 17	435	Trickling spring of slightly saline water in Wadi Thal.
Birel ᶜIseila ...	29 12 23	33 12 44	400	Well in Wadi el ᶜIseila.
Bir Um Dûd ...	29 12 14	33 17 19	776	Well in Wadi Um Dûd.
Qattar Khaboba..	29 4 40	33 15 55		Trickling spring of good water in Wadi Khaboba.
Bir Malha	29 5 3	33 25 33	485	Three wells in Wadi Malha. Water brackish, but Arabs drink it.
Bir Nukhul ...	29 3 20	33 15 32	349	Small water hole in Wadi Nukhul. Water slightly salt and muddy.
Bir el Markhâ ...	29 0 0	33 13 14	48	Well at foot of hills on the north side of the plain of El Markhâ. Water brackish.
Qattar Dafari ...	28 59 57	33 15 33		Small springs and pools in the rocky floor of Wadi Dafari. Difficult of access.
Bir Rekîs	29 1 53	33 21 7	330	Well in Wadi Baba, recently opened by prospectors. Easy of access. Water good and fairly plentiful.
Bir el Thifeiria...	29 1 33	33 21 55		Well in a small tributary of Wadi Abu Thor.
Bir Nasib	29 2 19	33 23 57	448	Principal water source of this part of Sinai. Spring in Wadi Nasib, yielding copious supplies of good clear water, easy of access and used to irrigate a small garden.
Ain Abu Hamata.	28 59 51	33 22 32	455	Pools with good water near head of wadi.
Bir Abu Sibeikhat	28 57 54	33 20 52	433	Well recently opened in Wadi Shellal. Gave good supplies in the spring of 1914, but ceased to yield at the end of April.
Bir Um Hamd ...	28 57 47	33 22 32	535	Well in Wadi Um Hamd.
Bir el ᶜAdeid ...	28 57 47	33 25 37	680	Well at the north foot of Gebel ᶜAdeidia, in a small feeder of Wadi Sahu.

The above list comprises the water sources within the district which was mapped in detail. During reconnaissances carried out to the north-westward, and on the return journey to Suez (*see* Chapter V), the positions of a number of other sources were fixed more or less approximately. These are tabulated below. Where the position was pretty precisely determined by triangulation, it is given to seconds; positions indicated only to minutes are estimated from the time and direction of marching.

Name.	Lat. N.	Long. E.	Alt above Sea.	Remarks.
	° ′ ″	° ′ ″	Metres.	
Bir Mofaqa ...	29 17	33 9	455	Well of good water, surrounded by a conical rubble-pitched excavation. No palms. Perennial supply.
Bir el Barazi ...	29 20	33 10		Well near junction of Wadi Watâ with Wadi Abu Qada. Said to yield perennial supplies of good water.
Bir Abu el Gawari	29 18	33 14		Water rather salt. Palms.
Bir Himeiyid ...	29 17	33 13	450	Pool of good water in narrow gully off Wadi Watâ, accessible to camels.
Bir Gharandel ...	29 16	32 58	60	Shallow well among rushes in Wadi Gharandel. Perennial supply of slightly salty water.
Bir Useit	29 12 56	33 0 49	104	Shallow well in Wadi Useit, near small clump of palms. Water bad.
Bir Thal	29 9 32	33 4 26	130	Shallow well in lower part of Wadi Thal, near small palms. Supply perennial, but water bad; only fit for camels.
Bir Queisa	29 10	33 3		Well about one to two kilometres north of Bir Thal, near palms. Water bad.
Bir Bâqa				Well in upper part of Wadi Bâqa, said to yield abundant supplies of excellent water.
Bir Hileifia ...	29 34	32 58		Spring on road to Suez, near a spreading seyal tree. Water plentiful, running off by a tiny canal, but slightly salt and fouled by camel droppings.
Ayun Musa ...	29 53	32 39		Numerous wells, with houses and gardens, on the Suez road.

Geology.*

From no point of view is this part of Sinai more interesting than from that of the geologist. Within the compass of a square of some twenty-mile sides, there are to be found rocks of the Archean, Carboniferous, Cretaceous, Eocene, and Miocene systems. Not only are these rocks exposed with a degree of nakedness rare even in mountainous and desert lands; they are shattered by faults in a way that characterizes the area as one of the most highly disturbed tracts of the earth's surface; they are invaded by dykes and sheets of basalt which show the district to have been one of marked volcanic activity in past ages; and finally they have been sculptured into the most striking forms by the action of sub-aerial agents.

Ancient crystalline rocks, gneisses, granites, diorites, and porphyries, forming the foundation on which the sedimentary strata were laid down, are well exposed in the south part of the district.

The Carboniferous beds, separable into an upper and a lower sandstone group, with an intervening division of limestones, form caps to the crystalline hills in the south and disappear under the Nubian sandstone to the north. An interesting feature of the Carboniferous limestones here is the close resemblance of their fossil contents to those of similar rocks in Britain; nearly all the Carboniferous fossils of Sinai can be matched from the mountain limestone of Yorkshire and Derbyshire, while even the coal measures are not totally absent, being represented by thin carbonaceous bands in the upper sandstones, though unfortunately far too thin and inferior in quality to be of any economic interest.

Though Jurassic rocks have recently been found in the northern portion of the Sinai Peninsula, no clear evidence of the existence of any formation between the Carboniferous and Cretaceous has been discovered in this west-central region; it is, however, remarkable that no unconformity has been observed in or below the Nubian sandstone series, so that it is not impossible that this series may comprise deposits not only of the Cretaceous period, but of the entire interval between the Carboniferous and Cretaceous.

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* The geology of the district is more fully discussed in Chapters VI and VII.

Cretaceous beds are well developed in the northern and western parts of the region, and are magnificently exposed in the scarp of Gebel el Tih. The lowest member of the Cretaceous here present is formed by at least the upper part of a great thickness of Nubian sandstone, devoid of fossils; above this comes a series of limestones and clays of the various divisions of the upper Cretaceous, frequently rich in fossils. The white hills near the coast are mostly made up of Senonian rocks, a formation higher in the series than the highest beds of the main scarp of El Tih.

The Eocene is poorly represented in the region mapped in detail, being confined to small areas on the west. It consists here of clays and marls, with some thin limestone beds, containing a rather scanty fauna and presenting a marked difference from the great thicknesses of massive limestone which characterise the same formation in the northern part of Sinai and in Egypt.

Miocene deposits occupy fairly considerable tracts in the western part of the region, being found on the hills called Sarbut el Gamal and Musabaʿ Salâma, as well as to the north of the plain of Markhâ and round the mouth of Wadi Baba. They consist of conglomerates, grits, limestones, and shales, with comparatively few fossils.

To the Pleistocene and Recent period must be referred the gravelly coast plain of Markhâ and the great tract of drift sand called Debbet el Qeri.

Basalt sheets cover several square miles of the country; the principal locality is Gebel Farsh el Azraq, where a thick basalt sheet with well-marked columnar structure caps the sandstone of the mountain. Other patches are found south of the Wadi Shellal and on Gebel Sarabit el Khâdim; while a dyke of the same rock stretches across the plain of Debbet el Qeri and cuts through the Cretaceous rocks of the Tih escarpment, and other dykes traverse the Matulla range and the hills at the mouth of the Wadi Nukhul. The age of these volcanic outpourings and injections cannot be very certainly stated; but they are obviously younger than the Upper Cretaceous rocks which they penetrate, and probably all date from the Miocene period.

The tectonics of the region are extremely complex, and faults, some of them of gigantic throw, are everywhere in evidence. Tilting of the beds has taken place to such a degree near the major faults that

the originally horizontal strata are now nearly vertical. But over the greater portion of the district there is comparatively little folding, and the shearing at the lesser faults is commonly quite abrupt. Most of the faulting is Post-Miocene. As will be seen from the chapter on physical geology, the faults in the Carboniferous areas have a close connexion with the distribution of the iron and manganese ores there found.

The most striking feature of the district as regards its physical geology is the grand display which the deeply cut wadis furnish of the erosive action of running water. Wind action is also powerfully attested by the curious carving of exposed rocks and the immense accumulation of wind-borne sand on the plain of Debbet el Qeri.

Mineral Products.

So far as is at present known, the only mineral resources of this part of Sinai of commercial value consist of the manganese iron ores which occur in the Carboniferous limestone of the southern half of the area, especially in the Um Bogma District. These deposits, which are of considerable magnitude, were discovered by the late Mr. Barron, of the Geological Survey, in 1898; after careful prospecting, they have lately been considered worth working on a commercial scale, and a limited liability company has been formed to exploit them. The ore is found in bed-like deposits adjacent to faults. It consists of varying admixtures of the oxides of iron and manganese, suitable for smelting for the manufacture of manganese steel. The ore is to be shipped to Europe for smelting, as the absence of natural supplies of fuel in Egypt forbids its reduction in this country.

Turquoise occurs in certain places in the lower Carboniferous sandstone near its junction with the overlying limestone, and many old workings for this gem are to be seen, especially near the temple of Sarabit el Khâdim. But apparently the known deposits in this region are almost entirely exhausted, for in the course of an exploration of numerous old turquoise workings I found nothing of the smallest value as a gem. Further south, however, I am told there are turquoise mines which are still productive.

The fairly close correspondence of the Carboniferous beds of the region with those of Britain, and especially the finding of Lepidoden-

dron in the upper sandstones, suggested a keen look-out for coal on the horizon of the coal measures. But though carbonaceous matter has been found at this horizon within the area, and even a thin seam of actual coal traced further north, it must be stated with regret that there is no hope of workable coal being found.

A similar verdict must be given with regard to hydrocarbon marls. Rocks which stink of hydrocarbons when struck or heated occur in the Wadi Teyiba, and far more abundantly in the Wadi Abu Qâda further north; but their hydrocarbon content is too small for them to be sources of fuel. Their main interest lies in a possible relationship to the oil fields on the shores of the Gulf of Suez, which have yielded considerable quantities of petroleum and which are still under commercial exploration. This point is discussed on page 209.

Antiquities.

The Israelites probably passed through some part of this district; Gebel el Tih is supposed by the Arabs, probably erroneously, to be the "Mountain of the Wanderings," the plain of Markhâ has been identified with the "Wilderness of Sin," and water-sources in the Wadis Gharandel, Useit, and Teyiba have all been suggested as possible sites of "Elim." But the children of Israel have left no marks of their journeyings, and one seeks in vain for any sure trace of their progress.

Of the Ancient Egyptians, there is a remarkable structural relic still standing, though in a sad state of dilapidation, in the small temple of Sarabit el Khâdim, founded at least as early as the XIIth Dynasty, of which a view is shown on Plate II.* There are probably several ways of getting to this temple, which is situated in latitude 29° 2′ 14″, longitude 33° 27′ 28″, at an altitude of 735 metres above sea-level; the route I adopted to reach it was to ascend the little Wadi Um Themeiyim, a tributary of Wadi Ba'la, up to its head, and then to scramble up a high scarp and across the intervening hilly tract to the temple. The most striking thing about the structure, which has its main axis about 20° north of east, is its assemblage of rectangular monuments (steles) with semi-circular tops, which make it look like a graveyard from a distance. These steles are inscribed

* A plan and description of the temple, with translations of the inscriptions, is given by Dr. Birch in the "Ordnance Survey of Sinai," 1869, Vol. I. A later and fuller account, with a plan and numerous excellent photographs, will be found in Prof. Flinders Petrie's "Researches in Sinai," London 1906.

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CHAPTER II.

ACCOUNT OF THE SURVEY OPERATIONS.

Geographical Survey.

The general scheme of the geographical survey was designed to connect this part of Sinai with Egypt by a continuous network of triangulation, thus making all triangulated positions in the peninsula depend, like those of Egypt, on the Transit of Venus Station near Cairo as fundamental position. The Egyptian triangulation had already been carried over into widely separated parts of the peninsula by two routes starting from the Nile Valley net; one proceeding across the Suez Canal into Northern Sinai, the other extending from Qena across the eastern desert and the south part of the Gulf of Suez to Gebel Um Shomer, a very high peak in Southern Sinai. The peak of Gebel Gharib, and Gharib Lighthouse, which were two main points in the Egyptian net, were visible across the gulf from the mountains of Central Sinai. There was thus no lack of suitable points of connexion, and once a continuous chain of triangles could be carried over Central Sinai, with lengths and azimuths depending on a central base-line, the positions of all points in the new net could be independently determined from any one of the various points of junction. The degree of closeness of agreement of the various values for the position of any point, derived from the various connexions, would give a measure of the accuracy, not only of the new base and network, but also of the long stretch of the Egyptian triangulation between the points of contact.

Base Line.

The sandy plain of Debbet el Qeri was at once singled out as a suitable place for a base line, not only by its level nature, but also by the circumstance of its being overlooked by the great scarp of Gebel el Tih, on which commanding stations could be easily obtained in the first expansion from the base. A guiding principle in all desert triangulation, where economy of time and expense is no less an object than accuracy, is to endeavour, from a few commanding occupied

stations, to fix by intersection a large number of other peaks; and from the top of the Tih escarpment almost all the important peaks on both sides of the gulf for a distance of over 100 kilometres can be sighted.

In choosing the precise site of the base, I was guided not only by the consideration of getting a level stretch of ground for it, but also by the desire to get the two ends on slight elevations. I have found this latter point to be of great importance in desert work. Of course, there is always a little possible error in length due to slope of the line at the two ends; but errors from this cause can be reduced to very minute proportions by grading the slope and careful allowance for the inclination of the tape, while a high degree of accuracy in the base is of no value if there are going to be relatively large uncertainties in the angles observed at its ends to the expansion points of the triangulation net. By keeping the ends of the base rather high, one maintains the line of vision along the base clear above the ground, undisturbed by lateral refraction and free from blurring of signals, and later on, when the base is left and observations are taken down on to it from hill stations, it is a great advantage to have the base ends on small eminences. A single second of error of angle in expanding from a three-kilometre base will usually produce an error in the deduced length of sides of triangles equal to that resulting from an error of about two centimetres of base length; but two centimetres of base length is well within possible avoidance, while a second of angle is not so if the lines run close to the hot ground.

Reconnaissance for a suitable position for the base was carried out by trotting on camel back along likely looking lines, and the base camp was fixed at the further end of the line finally selected as most satisfactory. Then a theodolite was set up at the camp end of the base, and a line ranged out in the selected direction, by sending an assistant to place three or four ranging rods along it at about 200-metre intervals, signalling the assistant and lining the rods in with the theodolite. Afterwards the assistant and chainmen prolonged the line, continuing to place ranging rods at similar intervals till they reached the further end.

When the whole line was staked, the alignment was easily checked by seeing if all the ranging rods appeared behind one another when seen through a telescope from the camp end of the base. A moderate

amount of deviation might be permitted without sensible loss of accuracy in base length, for with 100-metre tape lengths a deviation of the further end of ten centimetres from the line will only produce an error in length of less than one in a million; and it was found possible to keep all the ranging within this limit by lining as far as possible from a theodolite at either end and ranging in between with a field glass.

The base line, nearly three kilometres in length, was measured with a 100-metre tape, which had been previously standardized at the Helwân Observatory and found to be correct at 28° C. under a tension of fifteen pounds; the coefficient of expansion was taken as one millimetre in the 100 metres per degree centigrade. The ground was carefully smoothed along the line, by making little embankments and cuttings across any places where the surface was uneven, and large flat-topped wooden pegs were driven in flush with the ground at intervals of a hundred metres. On to the pegs were nailed zinc strips, each with an engraved scale of millimetres running for thirty centimetres in the direction of the line; the pegs thus only needed to be placed so that their distances apart were within a few centimetres of a hundred metres, for the positions of the end-marks of the tape to be read on the scales, and any overlap or interval between the successive positions of the end-marks of the tape was measured by the difference of the scale readings.

The greatest source of uncertainty in base measurements where the tape is laid on the ground is always that arising from the difficulty of ascertaining the true temperature of the tape, which is usually somewhere between that of the ground on which it lies and that of the air above it. To avoid error from this cause, obviously the best time of day for the measurement is that when air and ground are approximately at the same temperature. In these deserts that time is about sunrise; the measurement was consequently begun in the grey of the early morning, as soon as there was light enough to read the tape, and by pressing the work on as fast as possible consistent with due care, the double measurement, out and home, was completed within an hour and a quarter. This speed was of course only reached after considerable rehearsal and drilling of the various helpers, and the alternate kneeling and sprinting tires one out for the day; but experience has shown that with a sandy surface and a hot sun it is

fatal to accuracy to attempt to extend the measurement over more than half an hour or so after sunrise, and since one cannot direct the men or supervise the work well in the dark, one has perforce to hurry it on in the short interval from three-quarters of an hour before to half an hour after sunrise. In cloudy weather, of course, one could take more time ; but in Egyptian and Sinaitic deserts one might wait months for a day of that character, with expenses running on at the rate of several pounds a day and men getting out of hand through idleness. In order to be convinced of the advantage of getting the work of this manner of base measurement through in the early very morning, one has merely to remember that a millimetre error of reading is only equivalent to the error due to a single degree centigrade of uncertainty of temperature in the tape, and an hour after sunrise this latter uncertainty may amount to 5° C. or more.

In the process of measurement, the writer and Mr. Richards acted as observers, and about a dozen intelligent Arabs were employed as assistants. One observer was at each end of the tape ; he was provided with a thermometer, a pea-whistle, pencil and note-book. The actual ends of the tape were held by two strong Arabs, each with a rope round his waist, to which the tape was attached through a spring balance. Each tape-holder was assisted by an Arab who watched the spring-balance carefully to see that the tape was kept under the proper tension. Another intelligent native was given a thermometer, which he placed under each tape near its middle and read the temperature. Still another, selected for his "straight eye," was told off to keep the tape straight when laid down, and acted as captain of the carriers. The remaining Arabs had to pick up the tape at some twenty metre intervals, running along with it between the measurements, and aid in keeping it straight.

The measurement was begun by opening out the tape from its reel in the early dawn, the forward observer going along the line with his end till he reached the first peg. The tape was laid down flat on the ground, and the two observers looked along it to see that it lay fair and straight, if necessary directing Arabs to move it until it was so. The two end-men then squatted behind their pegs, and kept the spring balances at the prescribed tension of fifteen pounds. The thermometer man placed his instrument under the middle of the tape, at the same time that the central portion of the tape lay straight. The back observer

went on his knees, placed the end mark of the tape over the centre of the end peg, and his thermometer under it, waited a moment till he thought the forward observer was ready to read on his scale, then blew his whistle, writing down 0·00 for the reading of his end of the tape and the temperature indicated by his thermometer. If his whistle was answered by a single blast from the forward observer, he took that to mean that the forward observer had simultaneously verified that the tension at his end was correct, and that he had read and recorded the position of the tape end-mark on his scale and the temperature of his thermometer placed under the tape. Three rapid blasts of his whistle meant that he was not ready, or that there was some uncertainty, and readings were taken again at both ends. Assuming all well, as answered by one blast of the whistle, all rose up, carrying the tape, and ran hard to the next length, where all was repeated. saving only that this time the back observer read the position of the end-mark of the tape on the zinc scale instead of setting it over the centre of the end peg. The thermometer man read his instrument under the centre of the tape at the moment he heard the whistle blown.

On reaching the further end of the base, the measurement was made a second time, going back to the camp end. On arrival at this end, each observer had a record of temperatures and scale readings for his end of the tape over the double journey, while the thermometer man had a record of tape temperatures for each tape length. The manner in which the scale readings were allowed for will be apparent from the subjoined table, in which (1) and (2) indicate the camp end and further end of the base respectively, while the length 0–100 indicates the stretch from the camp end to the first 100-metre peg, and so on. The scale readings are given in centimetres with decimals to the tenth of a millimetre; the odd end length was measured with a graduated steel tape which had been compared with the standard one. The temperatures on each journey were meaned and the proper correction applied to each measurement as a whole.

Base Measurement, Debbet el Qeri, December 31, 1912.

Section.	Outward. Mean Temperature of Tape = 8°·8 C.			Homeward. Mean Temperature of Tape = 10°·4 C.		
	Scale Reading; Back End.	Scale Reading: Front End.	Difference.	Scale Reading; Back End.	Scale Reading: Front End.	Difference.
	cm.	cm.	cm.	cm.	cm.	cm.
0— 100	0·00	13·27	− 13·27	0·00	13·62	− 13·62
100— 200	16·50	14·73	+ 1·77	13·60	12·22	+ 1·38
200— 300	23·15	15·83	7·32	12·69	5·92	6·77
300— 400	21·20	17·60	3·60	10·69	7·62	3·07
400— 500	19·03	14·96	4·07	13·86	10·11	3·75
500— 600	17·15	13·92	3·23	7·26	4·41	2·85
600— 700	17·80	11·89	5·91	12·72	6·72	6·00
700— 800	21·45	16·24	5·21	13·56	8·74	4·82
800— 900	20·75	10·44	10·31	23·81	13·88	9·93
900—1000	16·12	12·06	4·06	12·60	8·84	3·76
1000—1100	18·75	13·47	5·28	18·05	12·93	5·12
1100—1200	13·90	6·42	7·48	15·04	8·55	6·49
1200—1300	19·40	14·71	4·69	12·73	9·14	3·59
1300—1400	21·96	7·68	14·28	18·09	4·00	14·09
1400—1500	13·09	8·23	4·86	15·64	11·09	4·55
1500—1600	14·50	7·63	6·87	15·76	9·02	6·74
1600—1700	15·84	9·27	6·57	13·85	7·81	6·04
1700—1800	12·86	10·71	2·15	13·35	11·31	2·04
1800—1900	16 06	3·27	12·79	19·29	6·42	12·87
1900—2000	21·45	9·61	11·84	17·52	6·04	11·48
2000—2100	20·78	12·94	7·84	10·19	2·48	7·71
2100—2200	13·95	3·62	10·33	17·84	7·27	10·57
2200—2300	10·64	5·95	4·69	15·60	10·99	4·61
2300—2400	10·24	2·41	7·83	17·49	9·70	7·79
2400—2500	13·75	2·41	11·34	20·96	10·09	10·87
2500—2600	15·14	9·42	5·72	18·11	12·42	5·69
2600—2700	12·96	9·01	3·95	14·75	10·86	3·89
2700—2800	18·71	10·22	8·49	20·90	12·84	8·06
2800—2900	15·84	6·91	8·93	22·14	13·29	8·85
2900—2977	26·35	0·00	26·35	26·56	0·00	26·56
Algebraic sum...			+204·49			+196·32

Since under the tension of fifteen pounds (this being the tension used throughout the measurement) the tape was certified to be correct at 28° C., with an expansion coefficient of one millimetre of its length per degree centigrade, we have:—

Tape length at 8°·8 C. = 100 metres − 19·2 millimetres = 99·9808 metres.
" " 10°·4 C. = 100 " − 17·6 " = 99·9824 "

from which the two measurements give the measured length of the line as—

Outward.

	Metres.
29 tape lengths at 8°·8 C. =	2,899·443
1 odd length =	75·395
Scales +	2·045
	2,976·883

Homeward.

	Metres.
29 tape lengths at 10°·4 C. =	2,899·490
1 odd length =	75·397
Scales +	1·963
	2,976·850

The mean of these closely agreeing values gave 2,976·866 metres for the measured length of the base. This had, however, still to be corrected, firstly to reduce it to the horizontal by allowing for the slightly varying slope of the ground, and secondly to reduce the length to what it would be at sea-level.

In order to apply to the base length the correction for the varying slope of the ground, the line was divided into sections in which the slopes was sensibly uniform, and the slope in each section determined by ascertaining the levels of the points of inflexion by spirit levelling. It is well known that in any one such section the correction to the length is $\frac{1}{2}\frac{h^2}{l} - \frac{1}{8}\frac{h^4}{l^3} + \ldots\ldots$, where h is the difference of level of the ends and l is the horizontal distance between them. The second term was worked out for all the sections in the base where h is greater than $\frac{1}{20}l$, and the total for all such sections was found to be only 0·2 millimetre, which is negligible. The total corrections for all sections is thus the sum of the values of $\frac{h^2}{2l}$ for all the sections. The actual observed values of h and the deduced corrections are given in the following table.

Levelling of Base Line, Debbet el Qeri.

Distance of Point from Higher End of Base.	Depression below Higher End of Base.	h	h^2	$\frac{h^2}{2l}$
Metres.	Metres.	Metres.	Metres.	Metres.
0	0·000			
		2·205	4·85	0·0242
100	2·205			
		3·580	12·80	0·0640
200	5·785			
		3·608	13·00	0·0650
300	9·393			
		3·428	11·75	0·0588
400	12·821			
		1·350	1·82	0·0091
500	14·171			
		0·810	0·65	0·0030
600	14·981			
		0·600	0·36	0·0018
700	15·581			
		0·926	0·86	0·0043
800	16·507			
		0·815	0·66	0·0033
900	15·692			
		0·333	0·11	0·0005
1000	16·025			
		0·780	0·61	0·0030
1100	16·805			
		0·100	0·01	0·0000
1200	16·905			
		0·252	0·06	0·0003
1300	16·653			
		0·836	0·70	0·0035
1400	15·817			
		0·710	0·50	0·0025
1500	15·107			
		0·190	0·04	0·0002
1600	15·297			
		0·700	0·49	0·0024
1700	15·997			
		0·336	0·11	0·0006
1800	16·333			
		1·135	1·28	0·0064
1900	15·198			
		1·072	1·14	0·0136
1942	14·126			
		1·582	2·50	0·0446
1970	12·544			
		0·281	0·08	0·0013
2000	12·263			
		0·597	0·36	0·0257
2007	11·666			
		0·866	0·75	0·0040
2100	10·800			
		0·697	0·48	0·0048
2150	11·497			
		1·295	1·67	0·0167

Levelling of Base Line, Debbet el Qerl (*continued*).

Distance of Point from Higher End of Base.	Depression below Higher End of Base.	h	h^2	$\frac{h^2}{2l}$
Metres.	Metres.	Metres.	Metres.	Metres.
2200	10·202			
		2·405	5·80	0·0290
2300	12·607			
		1·006	1·01	0·0050
2400	13·613			
		0·195	0·04	0·0003
2465	13·808			
		1·482	2·20	0·0458
2489	12·326			
		0·167	0·03	0·0014
2500	12·493			
		1·652	2·73	0·0136
2600	12·145			
		0·765	0·58	0·0081
2636	14·910			
		0·531	0·28	0·0052
2663	14·379			
		1·005	1·00	0·0135
2700	15·384			
		0·224	0·05	0·0021
2712	15·608			
		0·296	0·09	0·0024
2731	15·312			
		0·662	0·44	0·0184
2743	15·974			
		0·620	0·38	0·0082
2766	16·594			
		0·576	0·33	0·0048
2800	17·170			
		2·094	4·36	0·0218
2900	19·264			
		0·834	0·71	0·0068
2952	18·430			
		0·762	0·58	0·0323
2961	17·688			
		2·916	—	0·3660*
2972	14·752			
		0·000	0·00	0·0000
29·74	14·752			
			Sum ...	0·9483

Thus the total correction for the variations in level along the line is 0·9483 metre, to be deducted, since the distance between the end points would have been shorter if the line had been everywhere horizontal.

* Calculated direct from the formula : correction $= 11$ metres $\left(1 - \cos \tan^{-1} \frac{2\cdot916}{11\cdot00}\right)$

The altitude of the centre of the base was known to be approximately 500 metres above sea-level, from aneroid readings. The reduction to bring the observed base length to its value at sea-level is $\frac{la}{r}$ where l is the length, a the mean altitude, and r the earth's radius. We thus have to subtract $\frac{2,974 \times 500}{6,370,000}$, or 0·234 metre, as the sea-level reduction.

		Metres.
Measured length of base		2,976·866
Correction for slope	−0·948	
" " altitude	−0·234	
		−1·182
Giving the final corrected length		2,975·684

Astronomical Observations at the Base.

The operations at the base line camp included not only the measurement of the length of the base, but also the determination of its azimuth and the latitude of the eastern end of it by astronomical observations. Of these determinations, that of the azimuth was by far the more important, as the observed azimuth was a fundamental datum for carrying on the triangulation. The observed latitude, on the other hand, could not possibly be the true latitude, on account of the proximity of the great scarp of El Tih, which would deflect the plumb line to the north by several seconds of arc. But a good deal of attention was given to the observation of latitude, because the difference between the observed value and that found by subsequent triangulations from points free from local attraction would give a measure of the disturbing influence of the mountain mass, and the enforced stay of over a week at the camp for base measurement gave a good opportunity of repeated observation on several nights.

The theodolite employed for the astronomical observations was the same as that used for the triangulation, namely a Troughton and Simms instrument with six-inch circles, read by microscopes permitting of reliable estimation to a second of arc, and provided with a good telescope having a magnifying power of about thirty diameters. The circle errors of this particular instrument were known from previous experience to be very small, the wiring of the diaphragm was extremely fine, and the level on the microscope arm was sensitive, the bubble moving over one division of its scale for a tilt of five seconds

of arc. The theodolite was placed on stout wooden pickets driven into the sandy plain, its axis being plumb over the eastern end of the base.

Preliminary observations having been taken for time and an approximate latitude, by altitudes of east and west stars and *Polaris* respectively, the azimuth of the base was measured on two successive nights, by observations of the angle between the direction of the base and of the small circumpolar star *51 Cephei* at its eastern elongation. The mark at the further end of the base was an ordinary *shamadan* (candlestick with spring feed and glass globe) carefully placed exactly over the end peg. On each of the two nights four observations to the mark and star were made, a pair in each position of the telescope. The results were :—

		Mark West of Star at Elongation.		
December 29, 1st pair	...	76°	35′	13·9″
,, 29, 2nd ,,	...	76°	35′	14·7″
,, 30, 1st ,,	...	76°	35′	24·3″
,, 30, 2nd ,,	...	76°	35′	23·4″
Mean	...	76°	35′	19·0″
Star east of meridian ...	...	3°	13′	1·0″
Azimuth of base line ...	...	73°	22′	18·0″ west of north.

For the observation of latitude, two methods were used: (1) that of observing the times of equal altitudes of three or more stars, and (2) that of meridian altitudes on both sides of the zenith. Each of these two methods has been found to give a much higher degree of accuracy than that of altitudes of *Polaris* and circum-meridian stars as usually described in text-books of field astronomy. The reason for this enhanced accuracy is largely due to the circumstances that in the first method the vertical circle is never read at all, and consequently errors of graduation are entirely avoided, while in the second method the readings of the circle are confined to a very small portion of its limb, so that only errors of graduation in this small portion can affect the results. In addition, refraction and collimation are eliminated in both methods without reversal of the telescope; this avoidance of "changing face" probably contributes to precision by diminishing minute disturbances of instrumental adjustments. The first method, by equal altitudes of three or more stars, having been described in a recent publication,* need not be further gone into here, but the second,

* BALL, "Geography and Geology of South-eastern Egypt," Survey Department, Cairo, 1912.

to the possibilities of which my attention was drawn by my colleague, Mr. Villiers Stuart, merits a short notice. It is really an application of the theodolite to the purpose of the zenith sector, which, as is well known, furnishes one of the most precise means of determining latitude. The theodolite is carefully levelled and the meridian reading of the horizontal circle found by sighting either to a star or to a point to which the azimuth is known. Pairs of stars are looked out in the Nautical Almanac which transit at about the same time and about at the same altitude on either side of the zenith. Let us suppose that the north star of a selected pair transits first. The telescope is put into the plane of the meridian by bringing the horizontal circle reading to the known meridian value, and with circles lightly clamped the north star is carefully bisected by the horizontal wire at the moment of transit, and both microscopes of the vertical circle are read. The horizontal circle is now unclamped, and turned through exactly 180°, so that the telescope is again in the meridian but now pointing southwards; *the telescope is never reversed in this process.* Just before the time of transit of the south star, the vertical circle is lightly clamped at about the meridian altitude, and as the star crosses the middle of the field it is carefully bisected with the horizontal wire and the microscopes again read. If h and h' are the observed altitudes, corrected for refraction, and δ and δ' the declinations, of the north and south stars respectively, it is obvious that the latitude of the place is:—

$$\phi = \frac{1}{2}(\delta + \delta') + \frac{1}{2}(h' - h).$$

It will be noticed that it is only the difference of the observed altitudes which enters into the calculation, and as the two altitudes are read on the same part of the circle, only the graduation errors of this small portion of the circle can affect the accuracy. Further, as the altitudes are nearly equal, only the *difference* of the two refraction corrections comes into the result, and consequently it is sufficiently accurate to use the mean refractions, as taken directly from the tables, without correction for temperature and pressure. Of course, the level is carefully read at each observation, and the effect on the altitude of any small displacement of the bubble from the centre of its run allowed for in the subsequent computation; or the correction for level may be avoided by keeping the bubble exactly in the centre of its run at both observations, touching up the clip screw if necessary just

before the star transits. There is ample time to get a perfect bisection, because the star is moving horizontally, and the accuracy is not sensibly affected if the bisection is made a little way off the meridian.

In regard to the relative merits of the two methods, with a six-inch theodolite read by microscopes and having a level sensitive to five seconds of arc per division, the two methods yield about an equal accuracy in the latitude, say within about 2″ from a single night's work.* The advantage of great simplicity, both in preparing a programme and in computation, lies with the second method, but the observations frequently have to be spread over a longer time than in the first. If considerable errors of graduation of the vertical circle are feared, or if a vernier theodolite be employed, the first method has immeasurably the advantage. In either method, a sensitive level on the microscope arm or vernier arm is a *sine qua non* for accuracy; a sensitive level is a necessity for all refined astronomical observations, but is of special importance in methods depending on only a small number of readings.

The following is a summary of the results of the latitude observations at the eastern end of the base line :—

First Method. By Equal Altitudes.

December	25,	from one north† and two south stars	29°	6′	10·8″
,,	27,	,, ,, ,, ,,	29°	6′	12·4″
January	2	,, ,, nine ,,	29°	6′	7·5″
		Mean ...	29°	6′	10·2″

Second Method. By Meridian Altitudes.

December	26,	from one north star paired with the mean of four south stars	29°	6′	10·8″
,,	28,	from the mean of three north stars paired with the mean of six south stars	29°	6′	9·6″
		Mean ...	29°	6′	10·2″

---

* It does not seem possible to exceed an accuracy of about 2″ in the latitude by a single night's work with a 6-inch theodolite, though the probable error as calculated from the results is frequently less than 1″. This is probably due in part to a slight difference in the refractions at equal altitudes on opposite sides of the zenith, and in part to the constancy, under similar conditions of temperature and wind, of certain minute observational and instrumental errors throughout the night's work; on a succeeding night, the conditions being slightly varied, the inequalities of refraction will have changed their distribution and the minute instrumental and observational errors may well have an opposite sign.

† The reason for only one north star being employed here is that the most convenient altitude (about 30°) for the observation happens to be nearly the same as the latitude of the place, and consequently only close circumpolar stars are available to the north: the effect of this is to restrict the possible north stars to be employed to a very small number, and usually only one can be taken in the course of the evening. The bisection can, however, be made with correspondingly greater accuracy on account of the star's slow motion, or 3 or 4 bisections of the same north star can be made at intervals of half a minute or so by touching up one of the levelling screws and allowing for the slight tilting from the level readings; so that the paucity of north stars is not so great a disadvantage as at first appears.

As will be shown further on (page 33) the true latitude of this point as determined by triangulation is 29° 6′ 14·3″; the difference of 4·1″ between the true and observed latitudes represents the local attraction of the plumb-line, together with the unknown error of observation. It is, however, interesting to notice that the observed latitude is too low, so that the difference is in the right direction for being largely accounted for by the attraction of Gebel el Tih, which would pull the plumb-line northward; and the magnitude of the discrepancy corresponds closely with what we might expect from a rough estimate of the mass of the attracting mountain.*

Base Extension.

The length and azimuth of the base line having been determined, the next step was to extend the measurement by triangulation to points on the neighbouring mountains, from which a good command of the country could be obtained. The net by which this was accomplished is shown in Figure 3. It will be observed that a quadrilateral with diagonals extends on each side of the base, while the four extension points thus reached formed themselves the corners of a larger quadrilateral with diagonals. This gives a base figure of remarkable strength, for not only could each of the three quadrilaterals be adjusted separately by the method of least squares, but there was also the condition that one could proceed from one of the base-quadrilaterals through the great enclosing quadrilateral to the other base quadrilateral, and

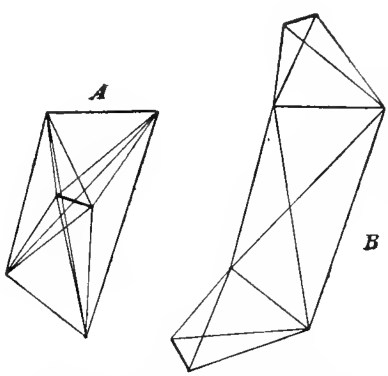

FIG. 3.—Base net. A, shows the actual net, the thick line denoting the base; while in B the two quadrilaterals from the base are imagined to be opened out, like flaps of an envelope.

* To get a rough measure of the attraction of Gebel el Tih on a plumb-line at the base point, we may assume the mountain to be a rectangular mass of density 2·0, with the nearest point of its face six miles from the latitude point, and extending twelve miles to the west, twenty-five to the east, with a breadth of thirty miles and a height of 1600 feet. The attraction of such a mass, calculated by the formula of Archdeacon Pratt (*Treatise on Attractions, Laplace's Functions, and the Figure of the Earth*, fourth edition, London, 1871, p. 73) comes out as 4·6″.

the length of the base found by going this way must agree with its measured value. It was not, of course, possible to go through this complicated adjustment in the field, but the observations were taken so as to enable the subsequent computations in the office to secure the highest possible accuracy in the deduced positions. In the field work, however, the northern base figure was adjusted by the method of least squares, the lengths being required with considerable precision in order to determine the geographical positions so exactly as to leave no measurable errors in the maps.

The horizontal angles at all points of the base net were measured on four arcs to eliminate circle errors. The average error of closure of the triangles was 4·4″; though not as small as was hoped for, this degree of accuracy was considered satisfactory in view of the base sights being taken over a flat sandy desert, and after adjusting the errors by the least square method the length of the line 3–4, on the top of Gebel el Tih, was found to be 11,238·4 metres. This gave an extended base from which to continue the triangulation over the area.

Field Determination of Geographical Position.

As the triangulation net was designed to connect at either end with other existing triangulations and thus form part of a larger network, final values for the geographical positions of the points could only be assigned after the conclusion of the field work and the complete reduction of the observations in the office. But it was necessary to obtain close approximations to the true positions at an early stage in the field operations, in order to place the graticules properly on the topographical field maps. It was further desirable to establish connexion with the other triangulations at as early a stage as possible, because if the various connexions agreed within the limits to be expected from a consideration of how far the work had proceeded, it would give a useful check on the accuracy of the measurements up to date; it is a good practice in all work of this kind never to neglect the change of a check, for a single mistake in the early stages may affect a whole series of computations, and the longer it is left undetected, the greater the subsequent labour of rectification.

From the base line itself no points of known position were visible, but as soon as station No. 4 on Gebel Sâlia was reached, the following

points were sighted, whose positions were known from my triangulation work in Egypt in the previous year:—

Point.	Description.	Latitude.			Longitude.		
		°	′	″	°	′	″
21	Gebel Um Shomer, summit ...	28	21	42·0	33	54	56·3
22	Gebel Gharib, summit	28	6	46·7	32	54	3·5
23	Gharib Lighthouse, centre ...	28	21	4·2	33	6	32·4

The directions of these three points from station No. 4, obtained by carrying on the azimuth from the base line, were:—

Gebel Um Shomer...	27° 45′ 46″	east of south.
Gebel Gharib	23° 22′ 18″	west of south.
Gharib Lighthouse...	18° 26′ 55″	west of south.

Any pair of these three points would form a triangle with station No. 4, in which all the angles were known from the azimuths, and the length of the line joining the two points being known from the given positions, the solution of the triangle would give the distances from the station on Gebel Sâlia to the known points, and the geographical position of the station could thence be easily calculated. The agreement of the situations found from the three triangles would afford evidence of the accuracy of the observed azimuth, while the calculated distances would furnish a check on the base length as soon as the points had been sighted from another station on El Tih and the distances thence found by direct triangulation from the measured base.

From the triangle, Um Shomer – Gebel Gharib – Gebel Sâlia, the position of the station on Gebel Sâlia was computed to be:—

Latitude 29° 11′ 17·0″; longitude 33° 25′ 27·8″

while the triangle Um Shomer – Gharib Lighthouse – Gebel Sâlia gave:—

Latitude 29° 11′ 16·7″; longitude 33° 25′ 27·8″.

The third triangle was not employed, as its apex angle was very acute, while the other two triangles were nearly equilateral. The close agreement in the case of the two triangles computed was very satisfactory, and the position of station No. 4 (Gebel Sâlia) was adopted as:—

Latitude 29° 11′ 16·8″; longitude 33° 25′ 27·8″.

Connexion with the base by triangulation gave the position of the latitude point at the east end of the base as:—

Latitude 29° 6′ 14·3″; longitude 33° 21′ 10·4″

and this was taken as the fundamental position for the field reductions. By a remarkable coincidence, the subsequent reduction and adjustment of the triangulation in the computation office gave precisely this same position of the base point.

As soon as the second station (No. 3) on Gebel el Tih had been occupied, and the same three distant points observed, a rough check was obtained on the base length, by calculating the triangulation distances to the points and comparing the results with the distances found from the azimuths alone. The points were so remote that the angles subtended at them by the relatively short line 3–4 were very small, being in fact between 4° and 7°, so that the check could only be a very rough one; but it was sufficient to prove the absence of any gross mistake. The comparison gave:—

Line.	Length found from Azimuths alone.	First Approximation to Length, found by Triangulation from Base.
	Kilometres.	Kilometres.
Gebel Sália to Gebel Um Shomer.	103·37	103·29
,, ,, Gebel Gharib ...	129·66	129·57
,, ,, Gharib Lighthouse.	97·71	97·61

The differences found were thus of the order of one in a thousand, corresponding to an error in angle of about 20″. This is about the precision of the single measurement made of the angles, and the check was accepted as satisfactory. It will of course be perceived that the length given above as found by triangulation was only the first approximation computed at this early stage of the work to furnish a rough check; as the triangulation progressed and the points were intersected with larger angles, the triangulation lengths were found to agree almost exactly with those deduced from the azimuths.

Triangulation.

The fundamental geographical position, that at the east end of the base, having been found with a precision sufficient to ensure that no measurable error would result on the field maps, and the base length

and azimuth having been satisfactorily verified, the triangulation proceeded rapidly, and in the course of four months the net was made to include some 140 triangulated points, of which eighteen were occupied, while an area of about 500 square kilometres was simultaneously mapped in detail on a scale of 1 to 50,000. In the second field season the triangulation was extended by a further twenty points, of which seven were occupied, and a further 500 square kilometres were mapped in detail. Triangulation points, other than sharp peaks, were marked by stone cairns. Horizontal angles were read with a six-inch microscope theodolite on four arcs for the base extension, and usually only on a single arc for other points, the sights being of course always made with the telescope in two positions, direct and reversed, to eliminate collimation errors. Most of the intersected points were sighted from three or more stations. The manner of reduction of the observations in the field was the same as that described on page 41 of my "Geography and Geology of South-eastern Egypt," Cairo, 1912. In the following lists, the positions given are those resulting from the final adjustment in the Computation Office after completion of the field work. Occupied stations are denoted by an asterisk (*), while a dagger (†) is used to distinguish points which have been intersected, not only in the present triangulation, but also from other triangulations connected with this one. The positions of these latter points have been assigned in the Computation Office after taking all the intersections into careful consideration; the positions as found from the various triangulations all agreed very closely, the differences only in a few instances exceeding 1″ in either geographical co-ordinate, so that the adjustments necessary were very small. Points marked with a double dagger (‡) were fixed by very acute intersections, and their positions are therefore only approximate. It will be noticed that the triangulation extends far beyond the limits of the area mapped in detail, including in fact a large proportion of the Peninsula of Sinai and an unmapped strip of Egypt along the Gulf of Suez; the list of triangulated points will thus be of service in future surveys of these districts, by furnishing a number of determined positions which will enable such surveys to be readily connected with existing ones. A sketch map indicating the positions of all the points triangulated outside the area of the detailed survey is given on Plate V.

MISSING

PAGE

List of Triangulated Positions in Sinai, within the Area mapped in Detail on Plate I.

Field Number of Point.	Name.	Mark.	Latitude N.			Longitude E.			Alt.
			°	′	″	°	′	″	m.
1	*East end of Base	Peg.	29	6	14·30	33	21	10·40	511
2	*West end of Base	"	29	6	41·95	33	19	24·95	496
3	*G. Shushet Abu el Nimran	Cairn.	29	11	21·88	33	18	31·92	1102
4	*G. Sâlia	"	29	11	16·74	33	25	27·82	1189
5	*G. Um Bogma	"	28	59	10·60	33	20	32·53	731
6	*G. Nukhul	"	29	2	35·25	33	15	49·86	674
8	*G. Samrâ	"	28	59	19·56	33	16	13·29	695
10	G. Sarabit el Khâdim ...	"	29	0	4·37	33	27	10·58	1096
11	G. Um Riglein, N. peak...	"	29	0	38·81	33	25	48·86	1017
12	G. ʿAdeidia	"	28	57	43·43	33	25	19·08	994
14	G. Moneiga	"	28	57	13·07	33	21	58·25	949
15	G. Um Bogma...	"	28	59	16·27	33	20	46·06	731
16	*G. Hazbar	"	29	4	30·68	33	20	39·81	576
17	*G. Musabaʿ Salâma ...	"	29	6	20·31	33	14	8·55	583
18	G. Sarbut el Gamal ...	"	29	8	15·63	33	12	51·08	642
19	*G. Abu ʿEdeimat	"	29	12	7·30	33	11	7·12	799
20	Hill S. of G. Um Riglein.	"	28	58	44·65	33	25	31·37	906
26	*Hill near Wadi Nukhul...	"	29	1	20·24	33	10	54·64	232
27	" " " " ...	"	29	2	31·38	33	11	44·97	334
28	G. Matulla	"	29	3	32·89	33	9	59·49	377
29	*G. Matulla	"	29	5	4·37	33	9	51·34	421
32	Hill at head of W. Um Sakran	"	28	59	8·44	33	21	41·98	821
33	Hill at head of W. Um Sakran	"	28	59	3·09	33	21	27·73	845
34	*G. Um Bogma	"	28	58	19·21	33	20	0·00	785
36	G. Samrâ, E. peak	Summit.	28	59	25·36	33	16	29·00	691
37	G. Matulla	Cairn.	29	2	45·84	33	9	43·35	398
39	*G. Um Rinna	"	29	5	0·22	33	24	45·89	592
64	G. Abu Treifia...	"	28	56	20·47	33	22	45·44	1024
66	*G. Ras Um Qatafa... ...	"	29	11	40·90	33	16	34·40	1054
68	Hill near Ras Abu Zenima	"	29	1	16·10	33	9	36·74	165
69	G. Matulla	"	29	4	9·25	33	9	56·22	390
131	*Hill N. of Markhâ Plain.	"	29	0	6·37	33	11	16·44	208
132	" " " "	"	29	0	35·12	33	10	35·04	219
141	" " " "	"	29	1	14·77	33	13	05·61	413
142	Hill W. of Wadi Nukhul.	"	29	3	39·03	33	12	35·72	342
143	G. Nukhul	"	29	3	22·43	33	14	54·60	585
144	Hill N. of Markhâ Plain.	"	29	0	11·28	33	13	11·82	134
145	* " " " "	"	29	0	19·30	33	12	49·18	169
146	* " " " "	"	29	1	5·07	33	14	21·16	428
150	*Hill near mouth of W. Baba	"	28	56	53·24	33	15	19·82	215
151	*El Mereighat	Cable Terminus.	28	58	29·80	33	14	59·86	84
152	*Hill north of El Qor ...	Cairn.	29	3	20·30	33	17	56·99	594
159	*Hill W. of W. Tilaʿ Gabir.	"	28	58	11·16	33	26	4·55	888
160	*Hill W. of W. Siheiya ...	"	28	57	42·74	33	27	31·58	892
162	G. ʿAdeidia	"	28	57	1·62	33	25	38·68	1044

List of Triangulated Positions in Sinai, outside the Limits of the Map on Plate I.

Field Number of Point.	Name.	Mark.	Latitude N.			Longitude E.			Alt.
			°	′	″	°	′	″	m.
7	G. el Ràqaba	Cairn.	29	1	41·16	33	41	55·31	1403
9	G. Ghorabi	,,	29	0	59·72	33	29	28·98	996
13	†G. Atairtir el Dahami ...	,,	28	55	46·19	33	23	30·71	1056
21	†G. Um Shomer	Summit.	28	21	42·02	33	54	56·29	2602
25	†G. Badia	Cairn.	29	32	36·46	33	19	1·84	1054
30	Hill near Wadi Teyiba ...	,,	29	6	17·95	33	7	23·86	301
31	G. Nezzazat	,,	28	38	17·15	33	18	25·50	640
35	‡G. Withr	,,	28	47	15·02	33	14	58·06	186
38	G. Thal (Useit of Adm. Chart)	,,	29	9	20·33	33	0	52·22	517
40	Hill NNW. of G. Badia...	Summit.	29	39	22·13	33	14	2·94	846
42	,, ,, ,, ...	,,	29	40	9·82	33	14	9·74	947
43	,, ,, ,, ...	,,	29	40	7·80	33	14	28·62	947
44	,, ,, ,, ...	,,	29	39	56·46	33	14	55·22	930
45	,, ,, ,, ...	,,	29	33	17·24	33	17	49·68	1065
50	Upper scarp, Gebel el Tih.	High Point	29	2	57·52	33	53	55·39	1625
51	,, ,, ,, ...	,,	29	1	24·65	33	57	31·53	1630
52	,, ,, ,, ...	,,	29	0	6·98	33	56	20·85	1570
53	G. el Tih, prominent corner...	Summit.	28	53	1·76	33	53	26·48	1612
54	G. Um ʿAlawi...	,,	28	33	58·90	34	2	12·70	2141
55	G. Musa	,,	28	32	18·39	33	58	26·03	2285
56	‡G. Katherina (or El Der).	,,	28	30	45·34	33	57	9·01	2646
57	G. Abu Rumail	,,	28	29	44·22	33	57	7·06	2624
59	†G. Serbal	E. Peak.	28	39	5·79	33	38	37·02	2078
60	†G. ,, ...	W. Peak.	28	39	14·14	33	37	30·62	2030
61	Peak near G. Serbal ...	Summit.	28	39	12·68	33	37	0·92	1803
62	,, ,, ,, ...	,,	28	39	52·51	33	36	8·05	1680
63	G. Um Lahm	,,	28	40	23·78	33	34	36·00	1286
65	*G. Hammam Faraún ...	Cairn.	29	11	20·15	32	58	19·12	495
67	Rock in sea near Abu Zenima	Nose.	28	53	49·71	33	10	17·70	0
70	G. Matulla	Cairn.	29	4	6·57	33	7	57·97	297
87	‡High hill S. of G. Bisher	Summit.	29	37	26·06	32	56	8·42	418
88	‡ ,, ,, ,,	,,	29	44	58·37	32	53	27·94	460
89	†G. Sin Bisher, SE. peak.	Cairn.	29	40	18·28	32	57	34·68	618
91	*Hill near Wadi Teyiba ...	,,	29	5	19·72	33	5	28·95	174
92	G. Thal	,,	29	8	37·96	33	1	22·93	357
93	Hill N. of G. Thal	,,	29	10	13·98	33	0	11·64	446
95	G. Krer (not highest point of range)	Summit.	29	16	31·46	33	6	31·25	640
96	†G. Koli	,,	28	27	9·83	33	55	56·06	2553
97	‡Mountain on Upper Tih scarp	,,	29	0	39·06	33	58	1·24	1575
100	Peak S. of G. Serbal ...	,,	28	31	48·58	33	34	58·08	1307
101	G. Himeiyir	Cairn.	29	1	39·36	33	33	4·92	890
103	†G. Banat	Summit.	28	45	20·03	33	37	45·53	1516
104	Mountain S. of G. Serbal.	,,	28	35	49·66	33	38	29·59	1670

List of Triangulated Positions in Sinai, outside the Limits of the Map on Plate I.

(continued).

Field Number of Point.	Name.	Mark.	Latitude N.			Longitude E.			Alt.
			°	′	″	°	′	″	m.
105	‡Mountain W. of G. Banat.	Summit.	28	45	44·86	33	28	21·02	957
107	G. Abu Alaqa	”	28	52	9·68	33	22	15·92	796
111	†G. Araba	”	28	28	35·50	33	22	6·82	696
112	†G. Abu Durba...	Sharp Peak	28	32	19·82	33	17	1·04	450
113	G. Nezzazat	High Point	28	38	42·51	33	17	57·07	572
114	”	”	28	38	17·24	33	17	19·64	462
115	G. Withr	Sandy Peak.	28	47	42·67	33	14	46·02	505
116	G. ”	Dark Peak.	28	47	40·00	33	14	9·69	457
122	*Bir Thal	Centre of Pool.	29	9	32·32	33	4	25·62	130
123	*Bir Useit	Headless Palm.	29	12	56·00	33	0	48·60	104
124	G. Abu Lassafa	Cairn.	29	15	59·10	33	8	33·55	729
126	*G. Ras Um Magharab ...	”	29	17	20 60	33	13	54·40	933
127	†G. Megmar	”	29	27	56·87	33	29	44·98	753
128	G. Dahák	”	29	26	20·42	33	9	6·21	917
129	†G. Khóshera	”	29	:8	46·20	32	55	48·90	381
133	Hill near sea	”	29	1	59·86	33	7	52·93	49
134	G. Néba	Summit.	28	50	19·13	33	27	18·13	942
135	*Hill near W. Teyiba ...	Cairn.	29	7	17·10	33	5	5·04	242
136	” Abu Zenima ...	”	29	4	16·02	33	6	3·50	129
137	*G. Tanka	”	29	5	23·18	33	4	17·81	74
138	Sinai Petroleum Syndicate	Flagstaff	29	5	35·89	33	3	53·32	19
139	G. Gushia...	Summit.	29	15	41·75	33	4	55·70	635
140	Hill SW. of G. Matulla...	Cairn.	29	2	20·78	33	9	3·89	242
147	High hill S. of W. Shellal.	Pinnacle	28	54	19·27	33	24	54·25	1038
148	” ” ”	Cairn.	28	55	39·51	33	20	45·98	688
149	” ” ”	”	28	55	17·06	33	18	16·66	575
156	” ” ”	”	28	55	30·12	33	15	21·40	335
157	” ” ”	”	28	54	35·57	33	16	42·82	490
158	” ” ”	”	28	55	50·99	33	16	11·89	346

* † ‡ For explanation of these signs, *see* p. 34.

List of Triangulated Positions on the Egyptian Side of the Gulf of Suez.

Field Number of Point.	Name.	Mark.	Latitude N.			Longitude E.			Alt.
			°	′	″	°	′	″	m.
22	†G. Gharib...	Summit.	28	6	46·69	32	54	3·49	1756
23	†Gharib Lighthouse... ...	Centre of Lantern.	28	21	4·28	33	6	32·44	50
24	†Zafarana Lighthouse ...	"	29	6	41·95	32	39	48·85	25
71	Mountain W. of G. Gharib	Summit.	28	6	26·20	32	46	32·21	980
72	" " "	"	28	4	59·86	32	41	1·42	981
73	" " "	"	28	10	18·46	32	40	57·63	891
74	" " "	"	28	10	25·29	32	39	55·42	1075
75	" " "	"	28	10	37·07	32	38	38·87	990
76	Mountain near G. Um Rabul	"	28	19	8·17	32	40	28·92	800
77	†G. Um Rabul	"	28	20	9·56	32	39	36·63	973
78	Mountain near G. Um Rabul	"	28	19	11·05	32	36	36·52	1004
79	Mountain near G. Um Rabul	"	28	22	39·17	32	33	36·22	824
80	Mountain S. of G. Um Tenassib	"	28	28	25·19	32	36	25·42	854
81	Mountain S. of G. Um Tenassib	"	28	28	39·48	32	35	55·33	838
82	†G. Um Tenassib	S. Peak.	28	30	0·61	32	34	3·27	1088
83	† " "	Central Peak	28	30	34·12	32	33	46·12	1104
84	† " "	N. Peak.	28	30	55·96	32	33	29·13	1062
85	S. Qalala scarp	High Corner.	28	54	58·59	32	25	39·28	1475
86	†Um Zenetir	Peak.	28	55	34·03	32	25	56·69	1201
94	†Newport Lighthouse ...	Centre of Lantern.	29	53	9·18	32	32	56·43	13
98	Mountain ESE. of Gebel Um Tenassib	Summit.	28	28	46·75	32	38	31·55	724
117	N. Qalala plateau	High Peak.	29	26	15·52	32	19	53·51	1136
120	†G. Thelemet	Cairn.	29	0	22·92	32	33	43·07	653

Altitude Measurements of Triangulation Points.

At every occupied station, vertical angles were measured to the visible triangulation points with the same theodolite as used for the horizontal angles, the vertical readings being made as far as possible in the middle of the day, when the refraction coefficient is usually most constant. The point No. 67, the nose of a rock awash in the sea, was included in the triangulation as the fundamental datum for the altitudes. Between occupied stations, the reciprocal observations of vertical angles gave the differences of height independently of curvature and refraction. For the intersected points, the ordinary formula for trigonometrical altitude measurement,

$$h = d \tan \theta + \frac{1-k}{2r} d^2$$

was employed, the refraction coefficient k being taken as 0·13 for all lines in Sinai itself.* This value of the refraction was found to give accordant results for land lines provided the observations were taken near the middle of the day, but for lines stretching across the Gulf of Suez into Egypt it was found to be too small; this was ascertained by including among the points some of those whose altitudes were accurately known from the Egyptian triangulation, and as a result it was found that for lines across the gulf 0·16 appeared to be a better value for k than 0·13. This increase in the refraction for lines across the sea, as compared with overland lines, is in accordance with experience in other surveys, and is doubtless mainly due to a flatter temperature gradient in the air over the sea as compared with that over the land.

As nearly all the intersected points were sighted from three or more stations, three or more values for each altitude were obtained and a mean value taken. The close agreement of the altitudes for the same point determined from the several stations of observation furnished a very useful check on the measurements; and in the cases where a point could only be sighted from two stations the agree-

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* As determined in the usual way from reciprocal observations, k is not quite correctly the coefficient of refraction, but a coefficient depending on all causes other than curvature which operate in a constant direction to elevate or depress the object sighted. The principal of these causes is refraction, but others may exist, such as the flexure of the telescope, referred to on page 43. The effect of flexure will vary as the distance, and not as its square, and thus strictly speaking it should be allowed for separately; its exact amount in the horizontal position of the telescope is unknown, but is doubtless small in comparison with that of refraction, so that no serious error in the resulting altitude can result by assuming it to vary along with refraction, the whole coefficient k being determined by reciprocal observations on lines of average length.

ment of the altitudes afforded also a proof that the point had been correctly identified at the second station. If a pair of intersections gave altitudes not agreeing with each other, it was accepted as a proof that different points had been sighted from the two observing stations, and the observations, both horizontal and vertical, were at once rejected.

From the close agreement of the altitudes found for the same points from widely separated stations, it is believed that most of the heights are correct within three metres; the error may, however, possibly amount to five metres or more in points near the south of the peninsula and on the Egyptian side of the gulf, the lines to which were very long and the points themselves only visible in the morning or evening. The altitudes found are given in the preceding tables of triangulated positions.

Comparison of Triangulated Positions with those obtained by the Ordnance Survey of Sinai in 1869.

Until the present survey was undertaken, the most accurate determinations of position and altitude of the Sinai mountains were those made by Captains Wilson and Palmer in 1868–1869, as recorded on pages 309–311 of the "Ordnance Survey of the Peninsula Sinai," large folio, London, 1869. It may be interesting to compare the positions now found with those arrived at by the older survey. The comparison is given below for a series of sixteen important points common to both surveys. The points are all well marked, being mostly sharp peaks of which the identification is certain. In quoting the levels of the older surveys, I have distinguished those depending on aneroid readings by an asterisk, as these cannot be considered to have anything like the accuracy of the others, which were found trigonometrically. The signs + and — prefixed to the differences indicate that the correction is additive or subtractive to bring the older values into accord with the new ones.

Comparison of Triangulated Positions.

Point.		Latitude.			Longitude.			Alt.
		°	'	"	°	'	"	m.
Gebel Sin Bisher ...	Wilson and Palmer	29	40	15·0	32	58	3·0	679*
	Ball	29	40	18·3	32	57	34·7	618
	Difference... ...			+ 3·3			−28·3	−61
Gebel Hammam Faraûn.	Wilson and Palmer	29	11	0·0	32	58	52·0	478*
	Ball	29	11	20·2	32	58	19·1	495
	Difference... ...			+20·2			−32·9	+17
Gebel Sarbut el Gamal	Wilson and Palmer	29	7	47·0	33	13	56·0	663*
	Ball	29	8	15·6	33	12	51·1	642
	Difference... ...			+28·6		− 1	4·9	−21
Gebel el Banat	Wilson and Palmer	28	45	12·0	33	38	31·0	1499
	Ball	28	45	20·0	33	37	45·5	1516
	Difference... ...			+ 8·0			−45·5	+17
Gebel Serbal	Wilson and Palmer	28	38	55·0	33	39	24·0	2053
	Ball	28	39	5·8	33	38	37·0	2078
	Difference... ...			10·8			−47·0	+25
Gebel Katharina ...	Wilson and Palmer	28	30	42·0	33	57	48·0	2602
	Ball	28	30	45·3	33	57	9·0	2646
	Difference... ...			+ 3·3			−39·0	+44
Gebel Musa	Wilson and Palmer	28	32	15·0	33	59	5·0	2248
	Ball	28	32	18·4	33	58	26·0	2285
	Difference... ...			+ 3·4			−39·0	+37
Gebel Useit (Gebel Thal).	Wilson and Palmer	29	9	0·3	33	1	26·0	—
	Ball	29	9	20·3	33	0	52·2	517
	Difference... ...			+20·3			−23·8	—
Temple of Sarabit el Khâdim. †	Wilson and Palmer	29	1	48·0	33	27	37·0	806*
	Ball	29	2	14·0	33	27	28·0	735
	Difference... ...			+26·0			+ 9·0	−71
Gebel Atairtir el Dahami.	Wilson and Palmer	28	55	52·0	33	24	17·0	1076
	Ball	28	55	46·2	33	23	30·7	1056
	Difference... ...			− 5·8			−46·3	−20

† I did not triangulate to the temple, but fixed its position by plane table resection from other triangulation points. The level was found by trigonometric observations to several points.

Composition of Triangulated Positions (*continued*).

Point.		Latitude.			Longitude.			Alt.
		′	°	″	′	°	″	m.
Gebel Abu Alaqa ...	Wilson and Palmer	28	51	59·0	33	22	55·0	800
	Ball...	28	52	9·7	33	22	15·9	796
	Difference... ...			+10·7			−39·1	− 4
Gebel Um Lahm ...	Wilson and Palmer	28	40	8·0	33	35	16·0	1269
	Ball...	28	40	23·8	33	34	36·0	1286
	Difference... ...			+15·8			−40·0	+17
Gebel Um ʿAlawi ...	Wilson and Palmer	28	33	57·0	33	2	45·0	2097
	Ball...	28	33	58·9	33	2	12·7	2141
	Difference... ...			+ 1·9			−32·3	+44
Gebel Abu Rumail ...	Wilson and Palmer	28	29	45·0	33	57	44·0	2569
	Ball...	28	29	44·2	33	57	7·1	2624
	Differenee... ...			− 0·8			−36·9	+55
Gebel Koli...	Wilson and Palmer	28	27	8·0	33	56	34·0	2510
	Ball...	28	27	9·8	33	55	56·1	2553
	Difference... ...			+ 1·8			−37·1	+43
Gebel Um Shomer ...	Wilson and Palmer	28	21	45·0	33	55	34·0	2575
	Ball...	28	21	42·0	33	54	56·3	2602
	Difference... ...			− 3·0			−37·7	+27

The differences found are smaller than those which usually exist between an exploratory survey and a subsequent connected triangulation, a circumstance explained by the extreme care and skill with which the Ordnance officers carried out their operations in the face of great difficulties. The mean corrections to be applied to the Ordnance positions to bring them into agreement with the connected triangulation are + 9″·0 in latitude, − 37″·4 in longitude, and + 10 metres in level. The irregularities of the differences, especially in the latitude, are readily explained by the methods which the Ordnance officers had perforce to be content with, in order to accomplish their work in the time available. The primary positions of the Ordnance survey (the first seven in the list of compared points) were fixed by latitude observations with a six-inch theodolite and a chain of azimuths

carried down from Suez. In those days of vernier instruments, when the modern method of relying only on the level and dispensing with the vertical circle was not practised, the utmost care would hardly enable a skilled observer to be sure of his latitude within 10″ or so from one night's observations, and there was further inaccuracy introduced both by the proximity of mountain masses which would deflect the plumb line, and by the necessity of connecting the point of latitude observation by a rapid triangulation to the trigonometrical station.

Captain Palmer states (on page 41 of the work already referred to) that his latitudes were determined by "meridian and circum-meridian observations of north and south stars, and altitudes of *Polaris* at any time"; but he does not indicate which of these methods were employed at the different places. If any of these observed latitudes depend on theodolite measurement of altitudes of *Polaris* alone, unpaired with a south star, errors of quite a large amount are possible, owing to a cause to which far too little attention is paid in books on field astronomy. With most theodolites, the latitudes found by *Polaris* and south stars respectively will be found to differ by a nearly constant amount, which often reaches 20″ or 30″, though a series of altitudes of the north or south star may agree among themselves to within a small fraction of this amount. In a similar way, times obtained from altitudes of east stars and west stars will usually show a systematic difference of a second or more of time. The result is that if a north or south star is alone employed, unpaired with one on the opposite side of the zenith, the latitude may be 10″ or 15″ in error, though derived from the means of a closely agreeing series of altitudes; and since altitudes of an unpaired east or west star may be 10″ or 15″ in error, the time derived from an unpaired star near the prime vertical may be wrong to half a second or more. The cause of this cannot be ascribed to an apparent displacement of the zenith by variations in refraction at the same altitude in different azimuths; for besides the fact that the differences found between stars on opposite sides of the zenith are of greater magnitude than we should think likely from such a cause, it is invariably found that the differences are practically constant for the same instrument and for observations at the same altitude, whatever the vertical plane in which they are taken, and whatever the time and place may be. The differences are in fact such as would be explained by altitudes taken with the same instrument, being uni-

formly in error by a small amount which is constant in sign and magnitude for the same altitude. "Changing face" does not eliminate this error, for, unlike collimation, it does not change its sign when the telescope is turned over. We are thus driven to the conclusion that the cause must be sought in the instrument itself, either in flexure of the telescope or in some slight play in its sliding parts. The time and latitude are correctly determined by taking the means of observations on both sides of the zenith, because the effect of flexure is then eliminated; but not from any series of observations, however long or careful, on a single star.*

The errors of longitude, apart from the circumstance of that of the fundamental longitude affecting all the others, would naturally be smaller than the errors of latitude, as Captain Palmer's connecting lines were run more or less near to the meridian. It is not easy now to ascertain what the error in the fundamental longitude of the Ordnance survey was, as the "Suez Hotel" cannot be with certainty located; but the fundamental longitude assumed was doubtless about 37″ too great, for if a constant correction of −37″ be applied to the Ordnance longitudes, there are only three points, among the sixteen compared, at which the longitude differs by more than 10″ from the presently accepted value. If we compare the differences of position of points included in any single "special survey" portion of the Ordnance work, as for instance Gebel Katharina and Gebel Musa, we find the difference of co-ordinates constant, proving the accuracy of the "special survey" within itself; it is only where the different "special surveys" had to be connected by traverses and other non-rigorous methods that we find irregularity. Any one who knows the character of Sinai mountains will wonder at the smallness of the differences when the methods then available are considered, and will cordially echo Captain Palmer's appreciation of the efforts of his staff, who chained over a hundred miles of mountainous country to connect his different triangulations together.

* In my own theodolite, which is an excellent six-inch Troughton and Simms instrument, the latitude derived from *Polaris* is invariably higher than that found from a south star, and the time found from an east star is always ahead of that found from a west one, the average differences indicating a flexure of somewhere about 10″ when the telescope is inclined at 30° to the horizontal. Other instruments which I have used show systematic differences of a similar magnitude, though not always in the same direction; an eight-inch vernier theodolite which I employed in the survey of Kharga Oasis in 1898 consistently gave latitudes from *Polaris* about 30″ *lower* than those from south stars.

There can, of course, be no doubt of the substantially greater accuracy of the positions found in the present survey over the older values. It is a case of comparing an extended single net of triangulation with a series of isolated small triangulations connected by traverses, and of comparing field observations of latitude made with a small vernier theodolite with latitudes deduced by continuous triangulation from a primary observatory. But as to *how* precise the new values are, it is not well to be too dogmatic, since some of the points have been triangulated with rather acute angles, and the accuracy of intersected positions falls off rapidly as the angle of intersection becomes smaller. But with the exception of the points marked with a double dagger in the list as having been sighted with specially acute angles, it may be hoped that all the new positions are correct within 1″ of either geographical co-ordinate. As regards the degree of reliability of the altitudes, these also are liable to errors, which increase rapidly at distances of over fifty kilometres or so, owing to the uncertainty of refraction, the effect of which varies as the square of the distance; but it is hoped that the altitude of no point, other than those above-mentioned as marked with a double dagger in the list, will be as much as ten metres in error, while the vast majority of the levels may be relied on to within a third of this amount.

Comparison of Observed Heights of Mountains and Hills with those figured on the Admiralty Chart of the Gulf of Suez.

A considerable number of the triangulation points of the present survey can be identified on the Admiralty Chart of the Gulf of Suez,* especially those on the summits of conspicuous mountains and hills. The identification is rendered easy by the accuracy with which the positions of peaks are shown on the chart, even where the names assigned on the chart are different from those given by my guides, or where the names are omitted altogether from the chart. The chart being on a rather small scale (about 1 centimetre to 3·4 kilometres, or 1 : 340,000), the positions cannot be scaled off much within 5″, but there is always a nearly exact agreement of the chartered positions with those I found by triangulation, even where the altitudes differ considerably. The following tabular comparison of heights refers

* Chart of the Gulf of Suez, No. 757, published by the Admiralty, April 21, 1873, corrected to June 1908.

only to points as to whose identification there can be no doubt. The names of the peaks are those given by my guides, and I have added the chart designation in brackets where this differs radically. The points are taken in order of latitude from north to south.

Peaks in Sinai.

Field No. of Triangulation Point.	Name.	Altitude on Chart. Feet.	Altitude on Chart. Equiv. in Metres.	Altitude by Triangulation (Ball).	Difference. Ball—Admiralty.
				Metres.	Metres.
65	G. Hammam Faraûn	1,620	494	495	+ 1
38	G. Thal (G. Useit)	1,670	509	517	+ 8
18	G. Sarbut el Gamal	2,370	722	642	−80
17	G. Musabaʿ Salama	2,200	670	583	−87
8	G. Samrâ	2,125	648	695	+47
13	G. Atairtir el Dahami	3,330	1,015	1,056	+41
107	G. Abu Alaqa	2,500	762	796	+34
134	G. Nêba (G. Um Meilihah) ...	2,950	899	942	+43
103	G. Banat	4,830	1,472	1,516	+44
59	G. Serbal, E. (highest) peak ...	6,680	2,036	2,078	+42
31	G. Nezzazat	2,050	625	640	+15
112	G. Abu Durba (G. Jehan) ...	1,420	433	450	+17
55	G. Musa	7,450	2,271	2,285	+14
56	G. Katharina	8,630	2,630	2,646	+16
111	G. Araba (G. Abu Huswah) ...	2,270	692	696	+ 4
21	G. Um Shomer...	8,530	2,600	2,602	+ 2

Peaks in Egypt.

Field No. of Triangulation Point.	Name.	Altitude on Chart. Feet.	Altitude on Chart. Equiv. in Metres.	Altitude by Triangulation (Ball).	Difference. Ball—Admiralty.
				Metres.	Metres.
120	G. Thelemet	2,175	663	653	−10
82	G. Um Tenassib (G. Ruahmi).	3,575	1,089	1,088	− 1
77	G. Um Rabul (flat-topped hill).	3,120	951	973	+22
74	Sharp peak...	3,425	1,044	1,075	+31
22	G. Gharib	5,740	1,750	1,756	+ 6

On the average, the altitudes on the charts are nine metres lower than my own, both in Sinai and Egypt. But the application of a constant correction of nine metres would scarcely bring the altitude of the individual peaks into closer agreement, owing to the irregularity of the differences. The largest differences found, *viz.* eighty and eighty-seven metres respectively, refer to triangulated stations quite close to my base, and my altitudes for these points being the mean of ten or more

very closely agreeing observations from widely separated stations, there can be no doubt that in the case of Sarbut el Gamal and Musaba'Salâma my figures are correct to within two metres; consequently, these large differences must be due to errors in the altitudes on the chart. The height of Atairtir el Dahami is equally accurately known, this point having been intersected from fifteen stations and the resulting altitudes all agreeing within three metres; so that here again the charted height must be considerably in error. In regard to the points situated in the southern part of Sinai and in Egypt, I cannot be equally certain of the greater accuracy of my figures, though in these cases too I believe my altitudes to be the more reliable, being the mean of closely agreeing values determined from two or more stations; but the sights were so long that small variations in refraction might easily render the resulting altitudes wrong by five metres, or possibly more. It is noticeable that in the case of conspicuous peaks like Gharib, Um Tenassib, and Um Shomer, which every surveyor who has worked in the district must have observed frequently, the agreement is very close, probably in consequence of the larger number of observations. My altitude for Gharib is derived from my previous triangulation of the Jemsa District, where it formed a main point in the net, and can hardly be in error by more than two metres, though I differ here by six metres from the chart; while at Um Tenassib and Um Shomer, of the heights of which I am less sure, I agree within two metres with the chart.

Variation of the Compass.

The compass declination was measured at two points, using a five-inch theodolite compass, with the following results :—

January 6, 1913,	Base camp, Debbet el Qeri ...	2° 8′ west.
„ 31, 1914,	El Mereighat	2° 17′ „

The instrument used did not permit of any great accuracy, but the mean of the two results, 2° 12′ west, is probably pretty close to the present average declination over the district mapped. Comparing this with three measurements made in the same district by Captains Wilson and Palmer in 1869, *viz.*—

Wadi Hommur	6° 30′
Mouth of Wadi Shellal	5° 33′
Temple, Sarabit el Khâdim	5° 40′
Mean ...	5° 52′

we deduce a secular diminution in the declination of 3° 50′ in forty five years, or an average of just over 5′ a year.

Over the greater part of the area, compass readings were found to be fairly reliable, owing to the absence of magnetic rocks. But in the neighbourhood of the basalt sheets and basic dykes considerable local disturbances occurred. The present survey was quite independent of the compass, which was only used to get a first approximation to the true orientation of the plane table, the final setting being always controlled by sighting three or more triangulation points, or by sighting two known points and measuring the distance to one of them tacheometrically.

Topographical Survey.

The topographical mapping was carried on by plane table concurrently with the other work, on a scale of 1 to 50,000, and the map which forms Plate I is a direct photographic reproduction of the two field sheets. Owing to the unavoidable passage of the alidade over the field maps at the very numerous stations (each sheet was in the field for four months and set up at about 800 stations), the lines have in places become a little rubbed, but it was felt that to redraw the maps in office would be liable to result in a little loss of accuracy in delineation, while consuming considerable time and expense.*

In the field work of the topographical survey it was a matter of the first importance to compute and plot on the map the positions and levels of as many triangulation points as possible ahead of the detail surveying, so as to have a sufficiency of fixed points by which to orient the plane table by resection, and to determine the altitude of the theodolite axis at any plane table station by measurement of the vertical angles to two or more points, the distances to which could be scaled from the map. The necessity of having the triangulation points on the map at the earliest possible moment was

* The maintenance of the map in a condition so clean as to permit of its being directly reproduced by photography, after its months of travel in the field, requires that it shall be on good paper, drawn with good ink, and the greatest care exercised to keep it covered when not actually being worked on. I use Whatman's hand-made paper, with the "H P" surface, mounted on brown holland; a double-elephant sheet cut in two makes two field-sheets, with plenty of allowance for clamping on a plane table 60 × 40 centimetres. Of the bottled drawing inks I have tried, Wolff's Chinese ink in shilling bottles satisfied me best. Coloured inks are to be avoided; none that I have tried are at all permanent under long exposure to brilliant sunlight. If coloured lines are wanted, it is best to mix up small quantities from one's colour-box, choosing mineral colours which are known to be the most permanent. All lakes are fugitive; even Prussian blue bleaches a little.

met by intersecting points with the theodolite wherever possible during the triangulation, even though the triangles might be very acute; for as a rule, a triangle with one of its angles as small even as two or three degrees, would give the lengths of sides and position of points with as much accuracy as it was possible to plot them on the map, though of course it would not do to employ the lengths thus found in continuing the triangulation, for which purpose the best shaped triangles were selected. When it happened, as was frequently the case, that a triangulation point was required to be plotted on the map while it had as yet only been sighted from a single station, the single intersection was used to give the azimuth to it, and an approximation to its distance was found within about 1 part in 200 or so (*i.e.* to the limit of practical accuracy of plotting of lines of ordinary length on the 50,000 scale), by running out a short base to a subsidiary point near the main station and measuring the angles at both ends of this short base. Usually the length of the short base was itself measured by triangulation, so that it was unnecessary to have level ground for it; in fact the short base ran almost invariably over very rough country. To make the process clear, let us suppose in the diagram, Figure 4, the points A B C to be points already fixed by triangulation, and that from C it was desirable to plot the positions of the three new points X Y Z, now intersected for the first time from C. A point C′ was selected, a few hundred metres distant from C, in a direction as nearly as possible "square on" both to the two known and the three unknown points.

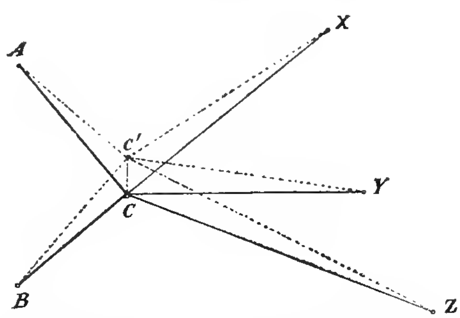

FIG. 4.—Diagram showing method of finding approximate distances to triangulation points from a short auxiliary base.

At C, horizontal circle readings were taken to C′, X, Y, Z, B, and A; then the point C′ was occupied and readings taken on C, B, A, X, Y, and Z. In taking these readings, it was unnecessary to read on more than one face, or even, as a rule, to read the two microscopes, for the errors due to collimation and excentricity are commonly so small in good theodolites as to be negligible for the purpose in view; but it was found to be an excellent plan for accuracy, and to save a great

deal of trouble in centering, to have *two* theodolites, one at C and the other at C′, the pointings between C and C′ being then made by bisecting the object glass of the telescope directed straight at you from the other station.* Another great advantage of having two theodolites was that they could be left up in place while the observations were reduced, and if any doubt arose about a pointing or reading, one had only to walk up to them and read again. The lengths C A and C B being known from the existing triangulation, solution of the two triangles A C C′ and B C C′ gave two values for the length C C′ of the short base, which by their agreement furnished a check.† Then the solution of the three triangles C C′ X, C C′ Z, C C′ Y, using C C′ as known base length, gave the distances of X, Y, and Z from C, and the positions of these points could thence be computed and plotted. The "Universal" slide rule of Nessler, which I invariably carry in my pocket on this work, enabled the triangles to be solved in less than half a minute each, with all the accuracy which is usually plottable. By reading vertical angles to the points at the same time, their levels could be determined with considerable approximation. As to how long it was desirable to make the short base, in order to get the required accuracy, this was easily arrived at by a little mental calculation. Suppose an accuracy of 1 in 200 was required in the lengths, and that the angles were liable to an error of 30″. That meant that the unmeasured angles at A, B, X, Y, and Z might be in error by 1′, but no more, and if the deduced lengths of short base and sides of small triangles were not to be more than one half per cent in error, the angles at the distant points had to be at least 200′, or say $3\frac{1}{2}°$. If the average distance to the points were five kilometres, the base had to be at least long enough to subtend $3\frac{1}{2}°$ at the points. Now a "square-on" base subtends roughly a degree if its length is one-sixtieth of the distance, so that in this case the base ought to be at least some 350 metres long to give the required accuracy. Frequently one had to

* An extra theodolite necessitates two extra porters, costing about three shillings a day for the two, and there are plenty of willing applicants for work of this sort in Sinai and Egypt. A day's work of ten hours costs something like £6 in wages of staff and camel hire: so that if the two extra porters save only half an hour at a station, they have been worth double their day's pay, to say nothing of enabling more work to be done in a season.

† I make it a cardinal rule never to neglect the chance of a check in this class of work. If only one of the two points A or B is visible, a fair check is obtained by reading the distance C C′ directly with a tacheometer and staff, and seeing that this agrees with the length found from the single triangle.

be content with a shorter base than one would like, owing to the local conditions; but *any* process of theodolite measurements, however small the angles, is usually better than plane table intersections, and if it was known that the conditions were bad, one endeavoured, on the one hand, to compensate by more exact sighting and reading of the angles, and on the other hand, to employ the approximately determined points as little as possible in resections, and then only in positions where a small error in their positions was of no great consequence. Whatever error there might be in the position of a point thus approximately placed, one always knew that the point was on the line drawn through it from the observing station, and so long as one was near this line in the field, a small error in the plotted distance was of little effect on the accuracy of resections made from it, while in marching to a distant point it was a very great advantage to know its position pretty exactly.

On an average, plane table stations were taken about a kilometre apart, points being selected whence three or more triangulation points were visible for fixing the position by resection, and whence a good view was obtainable of the immediately surrounding country. In the mountainous regions three or four stations had frequently to be taken within a square kilometre in order to overlook the country properly; and when, as sometimes happened, a station best adapted for seeing the close-in country was found to be one where resection could not be practised owing to lack of visible triangulation points, the position was fixed from a tacheometric reading on to a neighbouring plane table station which had itself been fixed by resection, using the compass for a preliminary orientation and subsequently adjusting by sighting a distant triangulation point. Between stations, the plane table, covered with a canvas cloth to keep the sheet clean, was carried on its tripod by a porter. Besides the plane table with its compass and alidade, the topographical equipment carried about the hills consisted of a five-inch tacheometer, two graduated staves, one or two ranging rods, and a six-inch theodolite (the same as used for triangulation). The tacheometer was always set up close alongside the plane table, and the level of its axis found by a slide rule reduction of the vertical angles to two triangulation points, using the scaled distances from the map.

In the more open parts of the country, distances to sketching points were found by sending round the two staff men and taking readings on their staves with the tacheometer. The accuracy aimed at in the location of sketching points was that all should be plotted within half a millimetre of their true position on the sheet; the scale being two centimetres to a kilometre, this meant that all distances had to be correct to twenty-five metres. It was consequently unnecessary to reduce the intercept-readings to the horizontal unless the lines were highly inclined, in which case the reduction was made in a few seconds on the spot by the "Universal" slide rule; the same instrument was used to find differences of level when required. The staves employed were four metres long, of flat section, about twelve centimetres broad across the face, graduated in black and white as shown in Figure 5; using only two of the three wires in the tacheometer for long shots, each of the larger (fifty centimetres) divisions of the staff corresponds to 100 metres of distance, and each smaller one to twenty metres. Sometimes the staves were supplemented by four-metre ranging poles graduated into fifty centimetre divisions painted alternately red and white; estimations to twenty metres of distance could be easily made on these, and the poles are very easily carried. In cases where the distances to the staff were greater than 800 metres, and the staff consequently subtended less than the space between two wires, the measurement was usually made by reading the intercepts on either side of a little dust mark on the diaphragm to the wires above and below it, and adding the two together; it would be an advantage in this work to have an additional short scratch exactly half-way between the ordinary wires, in which case it would only be necessary to double the reading.

Fig. 5.—Graduation of tacheometric staff. Each small division is ten centimetres long.

But over by far the greater portion of the area it was impracticable to employ the tacheometric method, owing to the impassable nature of the country, which abounds in deep gorges and precipices. Sinai Arabs can climb almost anywhere if given time enough, but encumbered by their staves it would have meant wery slow work to get a sufficiency of sketching points tacheometrically; and tacheometry is

usually limited to distances of less than a kilometre by the impossibility of making the men hear one's shouted directions at greater distances, especially if a strong wind is blowing. Throughout the survey of the mountainous regions, the distances to sketching points were found by measuring short bases at the plane table stations, and triangulating from the ends of these short bases to the points selected. This method is one which appears not to be mentioned in books on topographical surveying, but in a country like Sinai it is the method *par excellence* adapted to accurate and rapid mapping. At first sight, triangulation looks a slow process, but by making use of various aids, and above all by divesting the triangulation of all refinements which would give an accuracy exceeding that plottable on the maps, it was found to be immensely quicker in practice than any other means available in mountainous country. The process will be best explained by a brief description of the procedure at a typical station, in the course of which will be indicated the considerations necessary, on the one hand for the maintenance of all the required accuracy, and on the other hand for the economy of time and cost.

Let us suppose, as a typical case, that we have arrived at the edge of a hilly plateau overlooking a deeply-cut wadi, perhaps a kilometre or so broad and three or four hundred metres deep. We walk along the edge till we find a point whence there can be seen a good deal of the wadi floor and of the hills beyond it, and whence at the same time three or more triangulation points are visible, and set up the plane table and tacheometer there. We next make a mental decision as to how much of the visible country it is desirable to map from this station; in this the chief guides are: (1) it is impossible to sketch correctly any feature of which the shape and structure cannot be seen with the aid of field glasses; (2) if features too far afield are included it may need a longer base than can be arranged at the place to get distances with the desired accuracy; and (3) due regard must be had to likely future movements, for if a certain feature is going to be more closely approached later on, it might be better to leave that part for mapping from another station; but as a rule, it is best to map all that one can clearly see the shape of from a station, because one can never be sure whether another station will be found better adapted for the purpose, one of the chief difficulties in the work being to find stations whence the structure of the country can be completely seen.

Having settled on the station and the extent of country it is desirable to map from it, we look about for a point suitable for the other end of the short base. In selecting this latter point, the considerations are: (1) it should be about "square-on" to the country which is to be mapped, *e.g.* if the country to be mapped is across the wadi, the base is best arranged about parallel to the wadi course; (2) the base must be long enough to give sufficient accuracy in the measured distances; (3) all the sketching points must be visible from both ends of the base; and (4) it is a great advantage if one or two triangulation points are also visible from the further end of the base. The desirable length of base depends primarily on the distance of the furthest sketching point that it is desired to fix. Suppose the furthest point to be estimated as three kilometres distant, or six centimetres on the map. If the location is to be correct to half a millimetre on the map, the length must be correct to 1 part in 120. And if the likely error of angular measurement is such as to leave a doubt of 1′ in the third angle of the triangles, these third angles must not be less than 120′, or 2°. Then we have to think what length of base is necessary to give this angle at the furthest point; it is easily seen that if the base is "square-on" to the point, its length in the above particular case must be at least 100 metres, and proportionately greater if the base has to be taken in a less favourable direction. There is no harm in making the base a little longer than this calculated minimum, but time will be wasted in walking to and fro if the length is excessive, while it will sometimes happen that the desired length is unobtainable, and then one has to decide whether to reduce the proposed amount of mapping at the station, or to endeavour to increase the precision of the short base and of the angular measurements, in order to compensate for the smallness of the angles of the triangles. In this latter decision, experience is the only guide, but after a little practice there is seldom any doubt as to which course to follow.

The further end of the short base having been determined on, an assistant is left there to set up the theodolite and point it on to the tacheometer at the plane table station, while the surveyor walks back and fixes his place by resection on the plane table and determines the altitude of the tacheometer axis; the latter is accomplished by taking a couple of vertical angles to triangulation points and reducing the observations with the slide rule.

The next step is to decide on the precise sketching points to which to observe. Sitting on a theodolite box close to the station, the surveyor makes a diagrammatic perspective sketch of the country spread out before him, accentuating its salient features and leaving out all subsidiary details. He then scrutinises with a field glass all the points in succession of which he thinks the distances will be necessary in order to sketch in the country accurately on the map. A look-out is kept for very sharp features, which can be readily recognized from both ends of the base and at the same time are so fine that pointings on them can be made with great accuracy; these selected points are numbered in order on the sketch. On peaks, the white streaks made by the droppings of birds make good marks; if there are a lot of streaks, the longest is taken; if only two, close together, the space between them is bisected. Cracks and joints in the rocks, especially two crossing ones, often furnish fine marks; also small white stones on a black ground, two stones lying one on the other, the centres of peculiarly shaped holes in rock faces due to weathering, cairns built by Arabs as landmarks, and sharp noses of hard rock at the corners of a plateau, furnish other good points on mountains. In wadis, the centres of particular tree trunks, or of small isolated bushes, or peculiar-shaped boulders, are the best things to look out for. And it is well to remember that though a very salient feature, such as a rounded hill top, may be devoid of anything quite sharp, it is generally possible to detect with a field glass some sharp feature on its face, which, though not the precise point to be sketched, is yet so close to it as to give the distance as nearly as it can be plotted. As to the distribution of the selected points, that is a matter of experience. At first one nearly always errs in taking too many points close in, and too few further off; but one soon learns what has been worth the trouble and what has not, and after a month's work fully ninety per cent of the selected marks will be found useful, while only now and then will one find that the selection has been insufficient adequately to control the sketching. A typical diagram of selected sketching points, taken from my field note book, is given in Figure 6; this refers to a station on a hill near Wadi el Khamila, where the base length employed was eighty-eight metres.

Once the sketching points have been decided on, to which the distances are required, no time should be lost in observing to them from both ends of the base, because illumination alters rapidly, and if much

time elapses, things which were perfectly clear become obscure.* For this reason, it is best not to have more than about thirty points in a single run. If, say, sixty points are wanted, they are best done as a rule in two batches of thirty each.

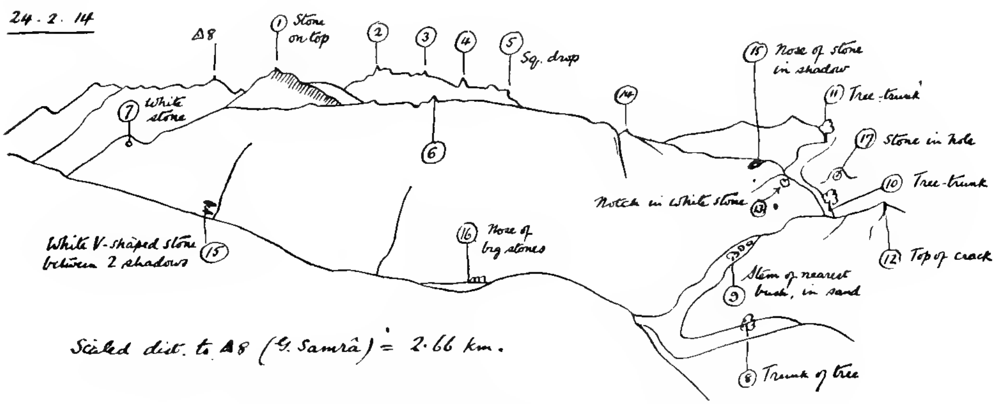

FIG. 6.—Diagram from field book, showing selection of sketching points.

It is advisable to observe the angles at the auxiliary station at the further end of the base before measuring those at the plane table station itself, partly because one or two points seen from the plane table station may prove to be invisible from the further end, and partly because it is an advantage to deduce the lengths at the plane table station immediately after the readings are taken there and forthwith proceed to plotting and sketching. At the further point, the zero of the horizontal circle, as read by the left hand microscope, is put on to the centre of the object glass of the tacheometer at the plane table station, then the circle is read (left hand microscope only) on each of the selected points in succession, finally closing up to the station again to verify that there has been no twist of the instrument; the readings are booked by an assistant. Then, after walking to the tacheometer at the plane table end of the base, its zero is put on to the further end of the base and readings taken on each of the sketching points in order, again closing up to the base to verify the absence of twist or

* Luckily, the skies of Egypt and Sinai are mostly cloudless. When the sky is mottled with drifting clouds, the moving shadows cause great difficulty, one moment throwing a peak into high relief, and the next obscuring it altogether. At such times, tacheometry or triangulation at very close quarters is the only satisfactory means of obtaining distances to sketching points.

slip. If the levels of any points are wanted, the vertical angles to them are read at the same time as the horizontal ones.*

The angles at the two ends of the base having been read, the length of the base may be found by sending a staff to the further end and reading the distance by the tacheometer. But it is best to get the length trigonometrically, by including in the series of readings a triangulation point or two, the distances of which are known from the map, and using the tacheometric measurement as a check; if no triangulation point be visible from the further end of the base, the tacheometric measurement will suffice, care being taken that there is no mistake in it, and remembering that any error in the measured base affects the mapping of all the points whose distances are measured from it.

A copy of the field book, corresponding to the sketching points shown in Figure 6, is given below. The figures in the column headed "theodolite readings" are the data booked from the observations, while the figures in the next three columns are deduced by calculation. The first step in reduction is to assign the angles subtended by the base at the sketching points, by deducting the sum of the two base angles from 180°; the second is to calculate the base length by slide rule from the observed triangulation point and to verify its agreement with the tacheometrically measured length; the third is to compute the distances of the points (by slide rule) from the observed data; and the fourth to deduce the levels of any points to which vertical angles have been read. In the copy of the field notes given below, the first point sighted is a triangulation point at the known distance, scaled from the map, of 2·66 kilometres, and solution of the triangle gives 87·9 metres for the length of the short base, agreeing satisfactorily with 88·0 metres as read directly by the tacheometer.

* If the collimation is adjusted at intervals, it is quite sufficient to read vertical angles for short distances in only one position of the telescope, and to read only one vernier, as single minutes of elevation or depression will give altitudes correct to a metre.

Triangulation to Sketching Points
from station on hill near W. Khamila, February 24, 1914.

Length of base by triangulation = 87·9 m.
" " tacheometer = 88·0 m. (adopted).

Point.	Theodolite Readings.*		Third Angle.		Angle† at Auxiliary Station.		Distance.	Remarks. ‡
	°	′	°	′	°	′	Kilometres.	
Δ8	207	33	0	52½	27	33		Scaled dist. = 2·66 km.
	26	40½						Gives base = 87·9 m.
1	213	52	2	12	33	52	1·27	Direct reading of base-length by
	31	40						tacheometer gave 88·0 m.
2	221	52	1	7	41	0	2·96	
	39	53						
3	223	58	1	8	43	58	3·09	
	42	50						
4	226	43	1	8½	46	43	3·22	
	45	34½						
5	229	21	1	18½	49	21	2·93	
	48	2½						
6	229	0	3	54½	49	0	0·97	
	45	5½						
7	200	23	1	41½	20	23	1·04	
	18	41½						
8	282	30	10	23	77	30	0·47	
	92	7						
9	272	53	7	16½	87	7	0·69	
	85	36½						
10	281	48	4	50	78	12	1·01	
	96	58						
11	274	31	3	29½	85	29	1·43	
	91	1½						
12	301	8	6	17½	58	52	0·69	
	114	50½						
13	276	8	6	25	83	52	0·78	
	89	43						
14	257	44	5	21	77	44	0·92	
	72	23						
15	207	48	2	48½	27	48	0·84	
	24	59½						
16	262	36	3	8½	82	36	1·59	
	79	27½						
17	280	35	4	20	79	25	1·14	
	96	15						

* In the pairs of readings on each point the upper reading is that at the auxiliary station, the lower that at the plane table station.

† Where the angle exceeds 90°, its supplement is given.

‡ This column serves for recording vertical angle observations when such are taken.

After a little practice, the process of triangulation to sketching points in the manner above described was found to be very rapid. A set of about thirty points generally occupied about an hour and a half, one half-hour being spent in the location of the base and the selection of the points, another half-hour in the observations, and a third in computing the distances by slide rule and plotting them with the alidade on the map. It was almost impossible for any considerable error, either of observation or reduction, to escape unnoticed; for when the points were plotted, if one of the distances were wrong it was easily seen to be so by comparison with the others, and it only took a few minutes to rectify the mistake by reading angles to it again and repeating the reduction. The instruments were of course left in place till the work at the station was complete.

At some stations, especially high stations overlooking extensive tracts of lower country, the sketching points fixed by triangulation could be supplemented by others obtained in a different way, depending on a consideration of the drainage. Suppose that two points three kilometres apart along a drainage line had been fixed and their levels determined by the triangulation process, it is obvious that the levels of intermediate points in the same drainage line could be easily estimated to a close degree of approximation, and distances to these points could be found by merely observing the depression angles to them and making a simple slide rule calculation, remembering that $d=h \tan \theta$, where d is the horizontal distance, h the difference of level between the station and the point, and θ the angle of depression. Let us suppose that a point was estimated to be 350 metres lower than the station, with a possible error of five metres, and the angle of depression to it measured as $12^\circ 40'$; the distance was found to be 1·55 kilometres, and this would be correct to 1 part in 70, because that was the possible amount of error in the assumed difference of level; the distance to the point would thus be correct to 0·02 kilometre, or about 0·4 millimetre on the map, which was within the desired limit of accuracy. It is obvious that the determination of considerable distances by this process was only possible at high stations, where errors of estimation of level could be kept small in proportion to the whole difference of height.

In particular cases, other methods of obtaining distances to sketching points suggested themselves. Indeed, one of the chief

pleasures in desert topographical work is the constant scheming out of devices to get measurements quickly and of sufficient accuracy for the particular purpose. A pretty case of this arose late one evening, after surveying down the Wadi Lahian to near its junction with Wadi Baba. We were at a place where distances to some half a dozen corners of the scarps around us were wanted to complete the sketching, and only a few minutes of daylight remained. It looked as if the work could not be closed up that night, and our camp being some six miles away, the journey would have to be made to the place again unless the mapping could be finished. Suddenly remembering that the scarps were all capped by the same limestone bed, which is here nearly horizontal, and that consequently all the points would have practically the same altitude above the theodolite axis, I observed the angular elevation to all the corners, including one whose distance was known from the part of the map already done; deducing the height of the limestone bed above the station from this known distance, the means was at hand by simple slide rule reduction to find the half dozen unknown distances, which being short did not need to be of very great precision in order to be within the half-millimetre of accuracy aimed at in the map. The observation, reduction, and plotting of the points was accomplished in a few minutes, and the sketching completed before it became too dark to see.

In the topographical sketching* at plane table stations, the shape of the ground was indicated by form lines, all of course drawn with a hard pencil on the map. Drainage lines and geological boundaries were distinguished by being drawn with a heavier pressure than the form lines. Levels were written in pencil in the places where they were to appear in ink later.

Inking up of the Field Map.

In inking up the map in the field, which had to be done as frequently as possible owing to the complexity of the pencil sketching and the danger of parts of the drawing becoming obscure by the passage of the alidade over them if left too long uninked, the aim was to leave the field sheet in such a finished state that on completion of the work

* While observing and sketching, it was found advisable to get an Arab to hold a sunshade over one, as one's helmet had to be discarded to get at the telescope or alidade properly, and sketching was much facilitated by diminishing the glare of the white paper.

the map could be photo-lithographed directly for publication without the laborious and costly process of redrawing in the office. It was not, of course, possible in the field to attain quite that degree of finish which is attainable in office work, as the surface of the field sheet could not be kept in a very perfect condition through the months of exposure to the weather; but by taking every precaution to preserve the surface of the sheet from damage, and exercising great care in the inking up, the resulting map was not so very far behind an office drawn map in finish, while the slight inaccuracies inseparable from any hand copying process were entirely avoided.

The design of direct photo-reproduction of the field map demanded of course that it should be inked up entirely in black, and forbade the use of colour. Drainage lines were shown by continuous black lines, and geological boundaries by fine hair lines. For the hill shading, which formed so important a feature of the map, the form lines of the pencil sketching were translated by vertical hachuring, the lighting being assumed vertical. It was found that a far better picture of the topographical features of mountainous country, on the scale employed for the map, could be given by vertical hachuring than by form lines, and in addition the geological boundaries stand out much more clearly on a hachured map than on one where form lines are employed for hill features.

Whenever practicable, each day's work was inked up on the map before going on to the next, while not only was the pencil sketching at its clearest, but the ground was fresh in the memory, if indeed not actually visible from the camp. When bivouacking, the work had perforce to run on uninked for a few days, but in such cases special care was taken to preserve the pencil sketching from partial rubbing out, and additional sketches of intricate places were made in the note book to facilitate a correct delineation of form when an opportunity should occur for inking up to be done.

In the process of inking up, it was found best to follow a regular system of operations. Level numbers were written in first, close to the points to which they refer: on peaks, they were placed on whichever side they obscured least of the topographical shading; on passes they were written straight across.* Place names were

* Levels were only figured at important points such as peaks, passes, and wadi junctions, which can be readily identified on the ground; it was felt that "spot levels" at other places would give no real information, while they would necessarily block out some of the hill shading, which *does* give information.

next inserted, care being here also taken that while sufficiently close to the actual sites to leave no doubt of their application they obliterated as little as possible of the hill shading. Thirdly, drainage lines were drawn in. Fourthly, all geological boundaries. At this stage a tracing was taken of the geological limits, as they would become obscured later on the field map by the hachuring, though clear enough on the printed map when brought out by differences of colour of the different formations. Then fifthly, the hachuring of the hills was proceeded with, beginning with peaks and well marked scarps and finishing with the more uniform slopes. The work of hachuring was found to be far more easily accomplished on a plane table in the field than on a fixed board in the office, as the sheet could be rotated so as to enable every hachure line to be drawn towards one; and the tripod having jointed legs, the folding of these brought the table down to a convenient height to work at when sitting on a camp stool. In places where flies were numerous, the hachuring was done inside a mosquito net hung up in the tent. It was found best not to attempt to follow any rigorous system of making certain distances and thicknesses of hachures correspond to particular degrees of slope, because any such system requires that the degree of slope should be pretty accurately known, and this was impossible when the pencil sketching was by form lines and not contours; but of course the general principle of close and thick hachures for steep slopes, and more widely spaced and finer hachures for gentle ones, was followed so as to give as true a picture of the forms as possible. And I found it a very useful general rule to sketch the pencilled form lines in the field at about the same distance apart as the hachures would require to be in order to express the slope. In the case of plateaux surrounded by scarps, or plains surrounded by hills, hachures were not inserted over the plane surface, even where it had a considerable degree of inclination; for by leaving the surface white, its plane character was rendered apparent, and the slope could be easily indicated by inserting a few figured levels. In fact, it was made a rule not to hachure any area over which camels can walk easily; for in addition to being readily intelligible, the map thus acquires an additional value as indicating clearly the possible lines of travel, even where no actual roads exist.

Survey of the Coast Line.

Only about nine kilometres of coast line fell within the limits of the field sheets, and being all visible from the triangulation point No. 131, on a hill 208 metres high north of the Markhâ plain, it was mapped in a few minutes at that station by the method of vertical angles.*

Geological Survey.

The geological examination and mapping of the country was carried on concurrently with the triangulation and topographical surveying. The rocks were examined along all lines of march, small detours and halts being frequently made to examine and sketch interesting exposures and to collect fossils, while the geological boundaries were inserted at the plane table stations at the same time as the topographical sketching was done. Whenever a halt of a day or more had to be made for computation, or for any other reason, an endeavour was made to fix the camping place in a locality where geological studies could also be made and fossils collected. The insertion of the geological boundaries at the plane table stations secured a great accuracy in the geological mapping, because points on the boundaries could be included among the sketching points, and the boundaries themselves could thus be drawn as precisely as the topographical features. In the collection of fossils, the Arab guides, porters, and camel men rendered very useful assistance. With a little training, Sinai Arabs make excellent fossil collectors, for they have very sharp eyes and can climb like cats; using their feet almost like a second pair of hands, they will follow a fossiliferous bed round scarps and collect from the most dangerous looking precipices if stimulated by a very small reward for their finds. It is safe to say that without the aid of my Arabs the fossil collections made would not have been a quarter so rich as they are, and the whole amount spent in rewards for good finds in the two seasons was only a few pounds. When halting for a day or more at a triangulation point, my practice was to show the Arabs the fossils I had collected on my way there, and indicate to them the beds which they were to

* For details of the method, see the author's "A New Method of Coast Surveying," Survey Department Paper No. 21. Government Press, Cairo, 1911.

trace and search. From sunrise to sunset twenty or more sharp-eyed Arabs would be following round the beds for miles, and each man would bring back his collection at night and place it in a little heap near my tent. Next morning I would look over each heap in turn, rejecting the rubbish and giving a small payment for the fossils kept, a piastre ($2\frac{1}{2}$ *d.*) for a very choice fossil, and a farthing or so for poorer ones. At first the men brought a good deal of rubbish; they had an idea that a big fossil must be of more value than a small one, and some of them carried a hundredweight of stones for miles in this belief; but they soon learned what was wanted, and became very keen collectors. There was never any grumbling about the reward paid, even when a man got nothing for his day's finds; and though there was great competition as to who should find the most, I never found one of them pilfering from his neighbour's pile.

As remarked on page 62, the geological boundaries were inked up on the map daily, and traced before the topographical hachuring was done. This was because the field map had to remain uncoloured, in order to permit of its reproduction by direct photo-lithography later. I kept a sheet of tracing cloth, graticuled like the field sheet, on which the boundaries were traced up to date and the colours added, all the work being of course done on the dull side of the cloth; at the end of the work I thus had a complete tracing of the geological formations properly coloured, to serve as a guide for making the colour plates for the printed map.

CHAPTER III.

THE WADIS AND PLAINS.

As already mentioned (page 4) the drainage from the north-eastern portion of the mapped area goes to the Mediterranean at El Arish, while the rest of the tract drains to the Gulf of Suez. Owing, however, to the fact that the northern-trending wadis were not followed sufficiently far down their courses to make sure of their ultimate destination, the precise position of the dividing line between the Mediterranean and Gulf of Suez drainages has not been ascertained, except where it coincides with the scarp of Gebel el Tih. It will in consequence be necessary, in a systematic description of the wadis, to class together all the wadis draining northwards from the top of El Tih scarp, without regard to the sea into which they drain. In the remaining portion of the area, which forms the bulk of the mapped tract, the wadis all ultimately drain into the Gulf of Suez, and can be easily grouped according to the main basins of which they form arteries. These main basins are shown in Figure 2 on page 3.

Wadis Draining Northwards from the Top of El Tih.

Enumerated from west to east, the northward draining wadis whose heads are passed in going along the top of the Tih scarp are :—

Wadi Hemeitia.
Wadi Um Ethla.
Wadi Um Qatafa.*
Wadi Um Dud.*
Wadi Abu el Nimran.*
Wadi el Seleilmih.
Wadi Um Sora.
Wadi Abu Treifia.
Wadi el Ghuzul.

As will be seen from Plate I, only the heads of these wadis have been mapped. The most striking feature common to them all is the proximity of their heads to the great scarp of El Tih. Not a single southward-draining wadi cuts back more than a short distance into the face of the scarp, and frequently the top of the scarp forms only a narrow ridge separating the northward drainage lines from the southward ones, so that one may conclude the erosion at the face of

* These three unite together a few kilometres down from their heads.

the scarp to be gradually beheading the northward-coursing wadis. Another remarkable feature, especially of the more westerly of the wadis, is their very rapid fall, almost as steep as the Tih escarpment itself. Thus the Wadi Um Dûd falls from a level of about 950 metres at its head to 776 metres at Bir Um Dûd, a drop of over 170 metres in a horizontal distance of only two and a half kilometres; while the Wadis Um Qatafa, Um Ethla, and Hemeitia each drop over a precipice at a distance of less than a kilometre from the scarp.

Wadis Draining to the Gulf of Suez, South and West of the Escarpment of El Tih.

The following list contains all the wadis south and west of the Tih scarp of which the names have been ascertained and marked on the map, grouped in accordance with their place in the drainage system. The first column gives the main trunk wadis; the second, the tributaries in order from above downwards; the third, the feeders of the tributaries in a similar order; while the fourth gives the minor drainages flowing into the feeders. After the list will be found a description of the wadis, taken in the same order, so far as they fall within the area of the detailed map on Plate I; a reference to that map will make it easier to follow the descriptions.

WADI THAL ...	W. el Mileiha.		
	W. Um Seyala ...	W. Abu Darb.	
		W. Um Shian.	
	W. Um Lasafa.		
	W. el Ibeiriq.		
	W. el Beidâ.		
WADI TEYIBA ... (lower part)	W. el A'wag.		
	W. Watâ	Rod Themilt Hámid.	
	W. el Mozeira.		
	W. Abu Riteimat.		
	W.Hereiyibat.		
	W. el Muqáfa (south).		
	W. Um Zuweibin el Foqani.		
	W. Um Shebba.		
	W. Um Zuweibin el Tahtani.		
	W. Um ʿAtaf.		
WADI EL HOMMUR (upper part)	Rod el Ghada.		
	W. Abu Insakar.	W. Um Shiah.	
		W. Abu Rigim.	
		W. el Muqáfa (north).	
		W. El ʿImeira.	
		W. el ʿIseila. ...	W. el Makhruga.
			W. Um Radim.
			W. Hasni.
			W Kabrit.
	W. Abu ʿEdeimat.		

- Wadi Matulla.
- Wadi Nukhul ...
  - W. Menlâha.
  - W. Khaboba ......
    - W. Um Silla ...... W. Abu Hish.
    - W. Um Thora.
    - W. Abu Arta.
    - W. Mowerid.
    - W. Musabaʿ Salâma.
    - W. Matulla......... W. Hamda.
- Wadi Dafari ...
  - W. el Khamila.
  - W. el Maqnas.
  - W. el Beidâ.
  - W. Qasr el Sherîf.
- Wadi Baba ...
  - W. el Sih. ....
    - W. el Misheish.
    - W. Khamilat el Naʿqa.
    - W. Um Zerdab.
    - W. Baʿla. ....
      - W. Qattar.
      - W. Um Themeiyim.
      - W. Suwiq.
      - W. Abu Maraq.
      - W. Um Naml.
    - W. Zobeir.
    - W. Um Rinna.
    - W. el Lahian...... W. el Malh.
  - W. Ikhfi (lower part). W. Budaʿ (upper part).
    - W. Rueikna. ......
      - W. Regibt el Teis.
      - W. el Ghanam.
      - W. el Kiheila.
    - W. el Museina.
    - W. Kibeil.
    - W. el Girafi.
    - W. el Khiteit.
  - W. Nasib.
  - W. Moerid.
  - W. el Dibabat.
  - W. Um Thimeiyim.
  - W. Abu Thifeirat.
  - W. Kharig......... W. Khrêg Hamda.
  - W. el Banat.
  - W. Rekis. ....
    - W. Abu Thor.
    - W. Abu Hamata.
    - W. Himeirâ.
  - W. Abu Maghara.
  - W. Filk.
  - W. el Temmaria.
  - W. el Himeirâ.
  - W. Abu Themam.
  - W. Samrâ.
  - W. Shellal (called Wadi el Sâhu in its upper part).
    - W. Tilaʿgabir ...... W. Zahloqa [W. Siheiya.
    - W. Abu el Tiur.
    - W. el Fera.
    - W. Um Retema.
    - W. Marahil.
    - W. Kharaza.
    - W. Rekeis.
    - W. Um Seyelat.
    - W. Hasania.
    - W. Um Sakran.
    - W. Um Hamd. ... W. Abu Treifia.
    - W. el Hezeimat.
    - W. el Himeirâ.
    - W. Abu Natash.
- Wadi Sidri ... W. Budra.

Wadi Thal and its Tributaries.

Only the uppermost portion of Wadi Thal has been surveyed. Its head is at the foot of El Tih scarp, near an eminence of that scarp called Ras el Hemeitia, and from hence it follows a westward course with a rapid fall over a rough stony bed. At the head of the wadi are several tracks; one leads by an easy pass southwards into the head of Wadi el ʿIseila, while another ascends the Tih scarp by a steep and winding route. About two kilometres below its head is **Bir Qattar,** a trickling spring of slightly saline water issuing among palms from a ledge of dark grey basaltic-looking crystalline limestone; this dense rock evidently holds up the water. A view of this spring is shown on Plate VI. A little more than a kilometre further down the wadi is another water source called **Bir Thal*** ; this is a shallow pool in the alluvium of the wadi floor, among rocks and palms. The supply here is said to be perennial, but the quality of the water is bad, and it is only fit for camels. The floor of Wadi Thal falls from a level of about 680 metres near its head to 435 metres at Bir Qattar, and to 345 metres at Bir Thal, an average drop of about eighty metres per kilometre of its course, and the wadi bed is in consequence very rough and stony, as will be seen from the lower view on Plate VI, which shows the approach to Bir Thal from Bir Qattar. The tributaries mentioned below are much less steep and stony than the main wadi, because of their greater length for a similar fall.

Wadi el Mileiha is a tributary of Wadi Thal, entering from the north between Bir Qattar and Bir Thal; its course has only been mapped for a kilometre above its mouth.

Wadi Um Seyala, which enters Wadi Thal almost opposite to Wadi el Mileiha, drains with its feeders **Wadi Um Shian** and **Wadi Abu Darb,** the north-west faces of Gebel Abu ʿEdeimat. The heads all cut deeply into the limestone plateau and originate in steep amphitheatres.

Wadi Um Lasafa, which enters Wadi Thal from the south about half a kilometre above Bir Thal, drains the north-west spurs of Gebel Abu ʿEdeimat.

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* There is another Bir Thal in the same wadi, much nearer the sea, with good water. *See* p. 106.

Bir Qattar (Wadi Thal).

Bir Thal, showing the stony approach.

Of the **Wadis el Ibeiriq** and **el Beidâ**, only the heads have been surveyed; these wadis, which likewise drain the north-west spurs of Gebel Abu ʿEdeimat, enter the Wadi Thal below Bir Thal.

Wadi Teyiba and its Tributaries.

Wadi Teyiba derives its name "the good wadi" from the circumstance that of all the great wadis in this part of Sinai it is almost the only one up which baggage camels can be got at all times of the year without difficulty. If transport is paid for by the day, an expedition starting from anywhere near Abu Zenima will be advised by the Arabs to go *viâ* Wadi Teyiba into the interior, whether the destination be to the Gebel el Tih in the north, or to the temple of Sarabit el Khadim in the east, or to the mines of Um Bogma in the south. During the last year or two, however, the alternatives have been rendered less difficult by the construction of tracks in the Wadi Shellal and elsewhere by the mining companies, and unless time is no object Um Bogma is now much more easily reached *viâ* the Wadi Shellal.

The name Teyiba is only given to the lower reach of the wadi, from where it passes between the mountains of Sarbut el Gamal and Musabaʿ Salâma to its mouth on the coast, a distance of some twenty kilometres. In its upper part the same main drainage line is called Wadi el Hommur.*

Wadi el Hommur originates by the union of **Wadi el Aʿwag** and **Wadi Watâ**, both draining by numerous feeders the escarpment of Gebel el Tih a little east of longitude 33° 20′. The Wadi Watâ is joined by the **Rod Themilt Hâmid**, which drains the eastern faces of Gebel Shushet Abu el Nimran. From the junction of Wadis el Aʿwag and Watâ, Wadi el Hommur takes a southward course as a broad sandy valley past the sandstone peak called Ras Sad Gifeila, and then turns westward, receiving as tributaries the **Wadis el Mozeira** and **Abu Riteimat** from among the low sandstone hills to the south, and lower down its course the **Wadis Hereiyibat, Um Zuweibin el Foqani** and **el Muqâfa**, as well as numerous other unnamed feeders, from the hills on the north. Both the Wadi Hommur itself and all its tributaries are characterized by broad sandy floors with scattered bushes and very gradual fall, so that passage for baggage camels is

* This difference of names for the same wadi in its upper and lower parts is very common in Sinai. Thus the upper part of Wadi Baba is called Wadi el Sih, the upper part of Wadi Shellal is called Wadi el Sahu, and so on.

easy everywhere along them, except within a kilometre or so of the great Tih escarpment, where the heads become stony and steep. The south feeders of the wadi head in the sandy plain of Debbet el Qeri, over which there is easy passage into the heads of Wadis Khaboba, Kharig, and el Dibabat.

Below the point of influx of Wadi Um Zuweibin el Foqani, the Wadi Hommur contracts somewhat in width at a sharp bend, and then opens out again, coursing now between higher sandstone hills, from which it receives the drainage by **Wadi Um Shebba** on the south, and the **Wadis Um Zuweibin el Tahtani** and **Um ʿAtaf** on the north side. Contracting again to a width of only about a hundred metres, Wadi Hommur passes between the two considerable mountain masses of Gebel Sarbut el Gamal on the north, and Gebel Musabaʿ Salâma on the south, and from this point onward it becomes the Wadi Teyiba.

Just where the wadi is narrowest between the two mountain masses, there is a very curious example of a "hanging valley," which forms a tributary draining from the heart of Sarbut el Gamal. This hanging valley, which bears no name, is quite inconspicuous from Wadi Teyiba, as its mouth is a vertical drop of some fifty metres; but it can be reached by a winding track up the scarp, practicable for unloaded camels, and once the precipice at the mouth is surmounted the going is quite good, the wadi expanding into quite a big one, with plenty of bushes. The track up the scarp has been made by the Arabs in order that their camels may reach the feeding ground above.

Immediately after passing Sarbut el Gamal, Wadi Teyiba opens out again into a broad sandy valley with low banks on each side. Its further course to the sea is outside the limits of the detail map; it continues eastward for about seven kilometres beyond the western edge of the sheet, then turns southward and reaches the coast a little north of Ras Abu Zenima. In the lower part of its course the wadi bed becomes very stony in places, with step-like sills of rock, and there are palms and tamarisks and springs of brackish water*; the road leaves the wadi-bed near the springs and proceeds over the low bounding hills so as to avoid the stony obstructions.

* These springs are possibly the "Elim" of the Israelites; but other sites have also been suggested. *See* p. 104.

Rod el Ghâda is a small wadi which drains the broken country to the north of the hill range of Matulla by numerous narrow tortuous gullies and enters Wadi Teyiba from the south in longitude 33° 9′. From one of its heads there is a track into the head of Wadi Matulla, and thence one may either descend easily into the Wadi Khaboba, or cross to the west side of the Matulla range by a rather steep pass.

Wadi Abu Insakar, an important tributary of Wadi Teyiba, heads in the scarp of El Tih and a mass of white hills near Gebel Ras el Hemeitia, whence it pursues a southward course between Gebels el ʿIseila and Ras Um Qatafa for about eight kilometres, then curving westward passes between Gebels el Tihîa and Sarbut el Gamal and enters Wadi Teyiba in about longitude 33° 8′. In the first eight kilometres of its course, Wadi Abu Insakar receives from the east the drainage from a portion of the Tih escarpment by numerous feeders, of which the principal are the **Wadis Um Shiah, Abu Rigim, and Hamadia**; while on the west a number of steep narrow gullies cut back into the slopes of Gebel el ʿIseila. Just where the wadi turns sharply westward, it is joined by two small feeders from the sandstone hills to the south, called **Wadi el Muqâfa** (north) and **Wadi el ʿImeira.** A rather bad road leads over a pass at the head of Wadi el Muqáfa (north) down into Wadi el Muqáfa (south), and thence Wadi el Hommur is easily reached.

Wadi el ʿIseila, though a tributary of Wadi Abu Insakar, is of almost equal length with the latter, and of more importance as containing a well, **Bir el ʿIseila,** and having a pass at its head into Wadi Thal. It originates in the same mass of white hills as Wadi Abu Insakar, and follows a generally southward course, first between Gebels Abu ʿEdeimat and ʿIseila, and then between the lower hill masses of Gebel Gorlos and Gebel el Tihia. The length of its main channel is about fourteen kilometres, and the fall of its bed is from 577 metres near the white hills at its head to 220 metres where it joins Wadi Abu Insakar, an average of twenty-five metres per kilometre. The principal feeders of Wadi el ʿIseila are all from the east and south faces of Gebel Abu ʿEdeimat, into which they cut back deeply; they are called **Wadis el Makhruga, Um Radim, Hasni,** and **Kabrit.**

Of the **Wadi Abu ʿEdeimat** only the upper portion has been surveyed; this wadi originates on the west face of Gebel Abu ʿEdeimat, close to the triangulation beacon, with an almost precipitous drop, and thence pursues a south-westerly course.

Wadi Matulla.

The Wadi Matulla drains the western faces of the long Matulla range of hills, and reaches the coast a little south of the Abu Zenima anchorage. Only the heads have been surveyed in detail. One of these is important as leading to a pass and giving a short cut from the coast to the Wadi Khaboba for lightly loaded camels.

Wadi Nukhul and its Tributaries.

Wadi Nukhul originates between Gebel Nukhul and the elevated sandstone plateau of El Qôr. Its head is very steep, and it becomes at once a great valley coursing north-westwards between the great mass of Gebel Nukhul and the high sandstone hills to the east of it. About three kilometres below its head is **Bir Nukhul,** a small water hole in the alluvium of the wadi floor, which was yielding slightly salt and muddy water in February 1914. The well is tolerably easy of access from the lower part of the wadi, along which camels can get right up from its mouth on the coast; but above the well the progress is only possible for goats and sheep, owing to the steep and stony nature of the valley. A track zigzags up the hill-side close east of the well, but is so steep that even unloaded camels have difficulty in getting up; this track rises 160 metres in a horizontal distance of less than half a kilometre.

About two kilometres below the well, Wadi Nukhul turns westward, winding about among hills for a distance of some three kilometres as a deep groove, so narrow that in places it is impossible for two camels to pass each other. Then it opens out again into a small plain from which there is an easy road northwards into Wadi Khaboba. Wadi Nukhul now turns southward and runs for another three kilometres along the foot of a high range of white hills, after which it winds about considerably in a general westerly direction for some seven kilometres to debouch on the coast by a very narrow and inconspicuous opening among high white hills. The fall of the wadi floor from the well to the sea is 349 metres in a distance of fifteen kilometres, or an average of twenty-three metres per kilometre. Wadi Nukhul receives in the lower two-thirds of its course a great number of small tributary wadis from among the hill ranges on either side. In one of these, called the **Wadi Memlâha,** there are some small workings in the shales for nitre.

Wadi Khaboba, the only large tributary of Nukhul, is considerably longer than Wadi Nukhul itself, having a total length of about twenty-three kilometres. It originates in the sandy plain of Debbet el Qeri at an altitude of about 500 metres above sea. At its head it is broad and sandy, but soon plunges down over a precipice into a winding gorge among high hills. A little below the gorge is a trickling spring called **Qattar Khaboba.** About two kilometres below the spring, Wadi Khaboba opens out and runs for four kilometres westward as a broad sandy valley among low hills. Then it enters higher hills, contracting greatly in width and winding about like a snake for about thirteen kilometres before joining Wadi Nukhul. The whole of this portion of the wadi can be traversed by camels, but it is so shut in by high dazzling white hills that on a hot day the journey is very unpleasant, owing to the combined sheltering from wind and the intense glare and heat reflection of the rocks, which turn the place into a veritable oven. The upper part of Wadi Khaboba is more quickly and easily reached by following the Wadi Nukhul to the small plain referred to above, instead of going all the way up Khaboba from its mouth.

Of the feeders of Khaboba, one, called the **Wadi Abu Hish,** originating at the northern edge of the broken sandstone plateau of El Qôr, is a narrow wadi coursing north-westward, traversable by camels; before joining Khaboba it courses over a small sandy plain and is here called **Wadi Um Silla**. Another feeder of Khaboba, the **Wadi Um Thora,** drains the hills north-west of El Qôr and joins Khaboba from the south just above the precipitous drop in its floor. **Wadi Abu Arta,** which enters Khaboba from the north, drains the hills to the west of Debbet el Qeri, while **Wadi Mowerid,** a shorter valley close to and parallel with Abu Arta, forms a usual road from Wadi Khaboba to Wadi Hommur; both these wadis (*see* view on Plate VII) are very sandy, and it is interesting to note that much of the sand hereabouts is of a brick red colour, being derived from the disintegration of red Carboniferous sandstone. **Wadi Musabaʿ Salâma,** another feeder of Khaboba, drains the south and east faces of Gebel Musabaʿ Salâma, while the small **Wadis Matulla*** and **Um Hamda,** which join and enter Khaboba at a great bend

* It will be noticed that this wadi bears the same name as a larger one which goes direct to sea on the other side of the hill range. A pass over the hills connects the heads of the two.

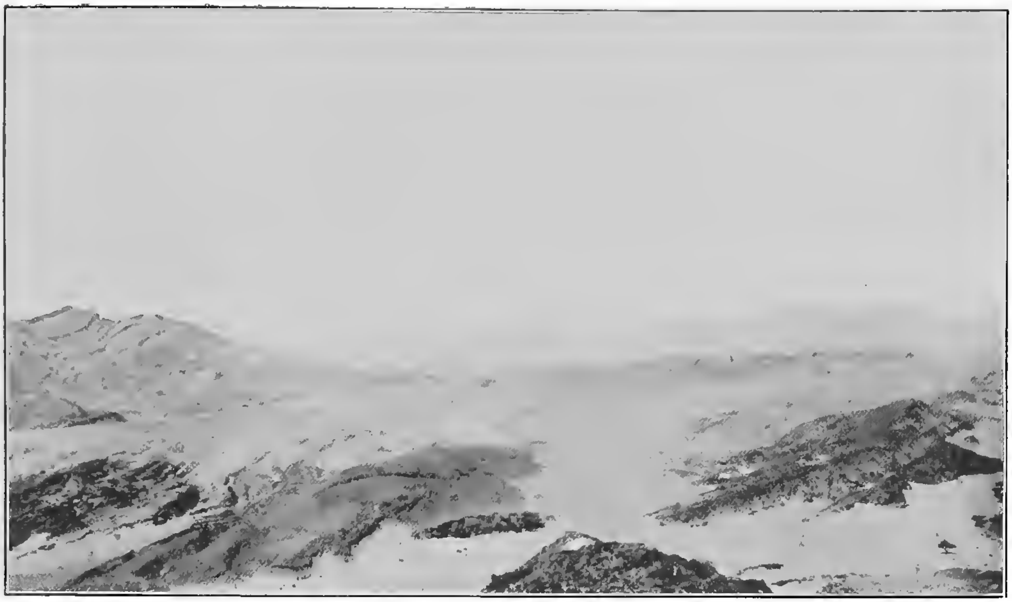
lower down its course, drain the white hills north-east of the Matulla range. Besides the above tributary wadis which bear special names, Khaboba receives a number of other feeders, some of them of considerable length and of very winding character, from among the hills to the west of Wadi Nukhul; the courses of these will be better grasped from the map than from any description.

Wadi Dafari and its Tributaries.

Wadi Dafari originates by the union of a number of broad sandy drainages from the broken sandstone plateau of El Qôr; these upper drainages bear no special names, but they form fair feeding ground for camels, and one of them contains the locality called **Mezra el Qôr,** where there are extensive low rubble walls, said to have been built by Arabs of old who grew crops of maize there after rain. A view of this place is shown on Plate VII.

At the point where the various drainage channels from El Qôr unite to form the head of Wadi Dafari, there is a precipitous drop over a thick limestone ledge, and the wadi plunges rapidly down in a south-westerly direction among the igneous hills; to avoid the precipice, camels turn a little to the south and descend by a steep and winding track, marked on the map, practicable only for very lightly laden animals. Even when the wadi bed is reached, it is necessary in proceeding down it to accomplish much of the way on foot, as the giant boulders in the floor make very difficult going for camels. About five kilometres down from its head, Wadi Dafari contains small springs and pools of water, called **Qattar Dafari**; these occur at a very steep drop in the rocky floor, barely passable by very lightly loaded camels even with the utmost care and skill on the part of the Arab drivers. A little below the springs, the wadi turns westward and emerges by a narrow gorge on to the plain called 'Elwa el Markhâ, across which it courses for about seven kilometres to reach the Gulf of Suez.

The principal tributaries of Wadi Dafari are **Wadi el Khamila,** a short wadi draining part of the Qôr plateau, and **Wadi el Maqnas,** a much longer valley which drains southward from Gebel Nukhul and joins Dafari about a kilometre above the springs. Another tributary, unnamed, drains the northern flanks of Gebel Samrâ.



View looking across Wadi Khaboba and up Wadi Mowerid.
(The mountain on the left is Musabaᶜ Salâma, and the great scarp of Gebel el Tîh is seen in the distance.)

Camp at Mezra el Qôr.

Like Dafari itself, these tributaries are very steep and stony, and are shut in by high rugged hills on each side. The main channel of Dafari falls from a level of nearly 500 metres at its head to about sixty metres where it emerges on to the coast plain, a drop of 440 metres in less than seven kilometres, or over sixty metres per kilometre.

Wadi el Beidâ, which drains a high range of granite hills south of Gebel Nukhul, and likewise the eastern faces of the limestone hills further west, is a short wadi, having a length of only some four kilometres from its head to where it debouches on the plain of El Markhâ. At its head there is a passable road, specially made by my camel men, leading over the hills eastward into one of the tributaries of Wadi Nukhul. The upper part of Beidâ is fairly flat and sandy, but the last kilometre before it reaches the plain is very steep and stony, so that camels proceed by a loop track (shown on the map) round the hills on the west. There are several small palm clumps near where the loop track joins the wadi, and some small water pools. Emerging on to the plain, which is here very stony, Wadi Beidâ courses westward and joins the Dafari drainage before reaching the sea.

Wadi Qasr el Sherîf is a small and unimportant valley which heads in the limestone hills to the north of the mouth of Wadi Baba, and emerging on to the coast plain at El Mereighât, ultimately joins the same drainage line as Wadi Dafari. It is said to derive its name from a ruin in or near it, which, however, I did not happen to see.

Wadi Baba and its Tributaries.

Wadi Baba, one of the most important drainage lines of the Sinai Peninsula, originates by the union of a number of other wadis bearing special names. As frequently happens in such cases, different Arabs have different ideas as to the point where the name Baba begins to be applied to the main channel; the majority of the guides, however, seem to regard Baba as commencing at the Dirret el Nasib, where the Wadis Ikhfi from the north, El Sih from the east, and Nasib from the south, join together. I shall accordingly consider Wadi Baba to commence at this point, and describe its course to the sea. afterwards considering the numerous tributaries.

Opposite the Dirret el Nasib, Wadi Baba is a broad valley with a flat sandy floor 400 metres above sea-level. After coursing west-

ward for about a kilometre, it narrows somewhat and turns south-westward between high hills. Then, broadening out again and going more southward, it receives the Wadis Kharig and El Banat from the north and west, and a little lower down the short Wadi Rekîs enters from the south-east. At this point is a well, **Bir Rekîs,** which has recently been excavated on the site of a former Arab well by the workers at the neighbouring mines; when I saw it in March 1914, this well was a shaft about a metre in diameter and five metres in depth, sunk in the wadi alluvium, with big boulders set round the mouth to prevent the sides falling in, and there was half a metre of very good clear water in the bottom. The level of the mouth of the well is 330 metres above sea.

About half a kilometre below Bir Rekîs, the short Wadi Abu Maghara enters from the north-west, and here are some fair sized date palms. Thus far down its course the wadi is broad and sandy, but it now becomes a narrow gorge, wandering on in a serpentine fashion south-westward, shut in by high mountains on either side, for some twelve kilometres before opening out again where Wadi Samrâ joins it from the north. The scenery in this twelve-kilometre gorge of Baba is extremely fine. The rugged mountains rise steeply on either side to heights of over a thousand feet, and the lateral tributaries drop over precipices hundreds of feet high to reach the main channel, while the stony monotony is pleasantly varied by extensive palm groves and little streams of water. The floor of this part of Baba, though it only falls at an average of fifteen metres in the kilometre, is in places very stony and so narrow that camels cannct pass each other, while at some seasons the passage is barred to transport by running water. Various stretches of the gorge, particularly those rich in vegetation, bear special names; the positions of these, **El Zira'a, El Lassafi, El Sharia, El Disa, and El Aqaba**, are shown on the map. The first three names are given because of the palm groves at the places, which have recognized ownerships. El Disa is a green tract with rushes, while El Aqaba is so named because there the wadi floor falls in a series of steps.

From where Wadi Samrâ enters it, Baba opens out considerably, the part below the point of influx of Wadi Shellal being specially broad, with a flat sandy floor. After making a sharp turn at the foot of the white hill-ranges nearest the coast, it cuts through these by a rather

narrow opening called **Lagham Baba** on to the coast plain, over which it spreads out like a fan to reach the sea by numerous very shallow channels.

Wadi el Sih, which forms the direct eastward prolongation of Wadi Baba, has only been mapped for about ten kilometres above Dirret el Nasib. At the place where it first enters the map (Plate I), it is a very broad and sandy valley with a gentle fall, coursing south-westwards. Receiving **Wadis Khamilat el Na'qa and Musheish** from the sandy plain to the north, and the shorter **Wadi Um Zerdab** from between two hill masses a little lower down, it soon becomes enclosed between high hills. Gathering the drainage of Wadis Ba'la and Zobeir from the south, Wadi el Sih then opens out into a small plain, where it receives Wadis Malha and Um Rinna from the north. It then narrows somewhat, passing between two high scarps, and receives the important Wadi Lahian from the south before emerging from an opening in the high plateau country and uniting with Wadis Ikhfi and Nasib to form Wadi Baba.

Wadi Ba'la heads at a pass between Mezra Abu Alfa and Gebel Sarabit el Khâdim. The pass, which is 765 metres above sea, and leads southward into **Wadi Tila'gabir,** is only practicable for very lightly loaded camels, and the same is true of the uppermost two kilometres or so of Wadi Ba la itself, which here is a narrow stony gorge. Coursing in an almost due north direction east of Gebel Um Riglein, Wadi Ba'la opens out slightly, receiving several short feeders from the mountains on either side; the principal of these feeders are the **Wadi Qattar,** which drains the north face of Gebel Um Riglein, and **Wadi Um Themeiyim,** which drains the western faces of the hills near the temple of Sarabit el Khâdim and forms a means of reaching the temple by a steep climb on foot at its head. Before reaching El Sih, Wadi Ba'la is joined from the east by **Wadi Suwiq,** a rather broad valley draining the north and east flanks of the Sarabit el Khâdim hill mass, and **Wadi Abu Maraq,** a shorter wadi, broad and very sandy; while from the south, at a sharp bend in its course about half a kilometre above where it joins Wadi el Sih, it receives the **Wadi Um Naml,** a short narrow wadi between high sandstone-capped ridges. The total length of Wadi Ba'la from the pass at its head to where it joins El Sih is ten kilometres, and the average fall of its floor is about twenty-two metres per kilometre.

Wadi Zobeir, which enters Wadi el Sih from the south about a kilometre below the point of influx of Wadi Ba'la, is a short valley about three kilometres long, with an easy pass at its head into Wadi el Lahian.

Wadi Malha, though only about five kilometres in length, is important both as containing wells and as forming a convenient route from the Wadi el Sih to the manganese deposits and ancient mine of Um Rinna. It commences by the assembling of a number of shallow drainage channels to the south-east of Gebel Um Rinna, and then falls rapidly, with much blown sand which makes rather heavy going in places, coursing southward on the eastern side of Gebel Um Rinna to join El Sih. **Bir Malha,** situated in the sandy bed of Wadi Malha about two and a half kilometres up from its junction with Wadi el Sih, consists of three wells yielding brackish water. There are some sheikhs' tombs, in the form of rectangular stone houses, near the wells, and some other Arab graves. To get to the Um Rinna mines, one continues up Wadi Malha for about a kilometre past the wells, then ascends the hills to the west, skirting the north side of the tributary wadi which heads close to the triangulation beacon.

Wadi Um Rinna, another short wadi on the west side of Gebel Um Rinna, forms a shorter cut from Wadi el Sih to the Um Rinna mines, but this route is impracticable for camels, and difficult even on foot, a steep scarp having to be climbed to get to the beacon.

Wadi el Lahian a northward-coursing tributary of Wadi el Sih, has a length of about ten kilometres, and is of importance as forming a convenient route from Wadi el Sih to the Wadi el Sahu. It originates at a pass, 700 metres above sea-level, on the eastern side of Gebel Farsh el Azraq ; the pass, though rather steep, is practicable for baggage camels if not too heavily loaded, and is marked by Nabatæan inscriptions on the variegated sandstone rocks. The upper part of Wadi el Lahian is narrow and stony, but opposite to Gebel Um Riglein it opens out considerably, and contains plenty of trees. At this point it receives the little **Wadi el Malh,** which drains the south part of Gebel Um Riglein and the north portion of the Mezra Abu 'Alfa plateau ; this wadi derives its name from some salt workings in it, which, however, I did not visit. A little lower down are some Arab store-houses, two of which are very conspicuously placed on rising

ground on the west side of the wadi, and just below them there is a pass leading westward down into Wadi Nasib. This pass is only a few metres above the level of Wadi el Lahian, but the drop on the other side is pretty steep. Below this place Wadi el Lahian continues a rather winding course, shut in by high granite hills, many of which have flat limestone caps on either hand, to join the Wadi el Sih just above where the latter leaves the high plateau country to form Wadi Baba. The going all along Wadi el Lahian is extremely good except close to its head, so that Arabs going from Bir Nasib to Wadi Sahu with heavily loaded camels usually prefer to descend Nasib and traverse the entire length of Wadi el Lahian rather than adopt the shorter cut by the pass above referred to.

Wadi Ikhfi, the upper portion of which is called **Wadi Budaʿ,** conveys to Wadi Baba the drainage from a great stretch of the escarpment of El Tih. Wadi Budaʿ originates by the coalescence of **Wadis Kiheil, el Museina,** and **Rueikna** (the latter having **Wadis Ras Ghanâm and Regibt el Teis** as tributaries) into a single channel. All these contributory wadis originate in the scarp of El Tih, with steep heads and flat shallow main courses over the sandy plain which lies between the foot of the escarpment and the hilly tract to the south. At their point of junction they are joined from the south-east by **Wadi el Kiheila,** which derives its name from its blackness, due to its coursing along a great dyke of basalt. Curving to the westward, Wadi Budaʿ, at first broad and sandy, soon contracts among the hills and drops into a gorge, where it is joined by the short **Wadi Girafi** from among the hills to the north, it then opens out and collects some lateral feeders, only to plunge down again over a precipice into the gorge of Wadi Ikhfi, gathering the drainage of **Wadi el Khiteit** from the north-west on its way, and ultimately uniting with Wadis el Sih and Nasib to form Wadi Baba.

Wadi Nasib, though only a short wadi some six kilometres in length, is in some respects the most important valley in this part of the peninsula, from the circumstance of its containing an exceptionally good water source, and as having been the site of copper smelting works of great antiquity. Wadi Nasib commences by the union of a number of small stony gullies near the pass into Wadi el Lahian referred to above, and runs a little west of north in a nearly straight line to join Wadi Baba. The wadi begins to widen out about

two kilometres below its head, and from this point onwards it is a broad wadi with abundance of acacia trees. About one and a half kilometres above Bir Nasib, in a little tributary to the west of the main wadi, is a stone house recently built by prospectors working on the manganese deposits, of which several patches occur in the hills hereabouts. **Bir Nasib,** views of which are shown on Plates II and VIII, is situated on the west side of the wadi about four kilometres up from its mouth, at a level of 448 metres above the sea. It is marked by palms and other trees, and some small stone huts, one of which is occupied by an Arab who resides at the place. The well, or more properly the spring, is a pool about a metre and a half in diameter by a metre deep, filling as fast as emptied with good clear water ; the water is lifted by a *shadûf* to irrigate a small garden near by. Amongst the plants cultivated in the garden is tobacco ; the dried leaves are sold to the Arabs, who state, however, that it is inferior to the imported product. Camels can get quite close to the pool. Extensive black heaps of copper slag, the refuse of ancient Egyptian smelting works, cover the ground north-east of the well.

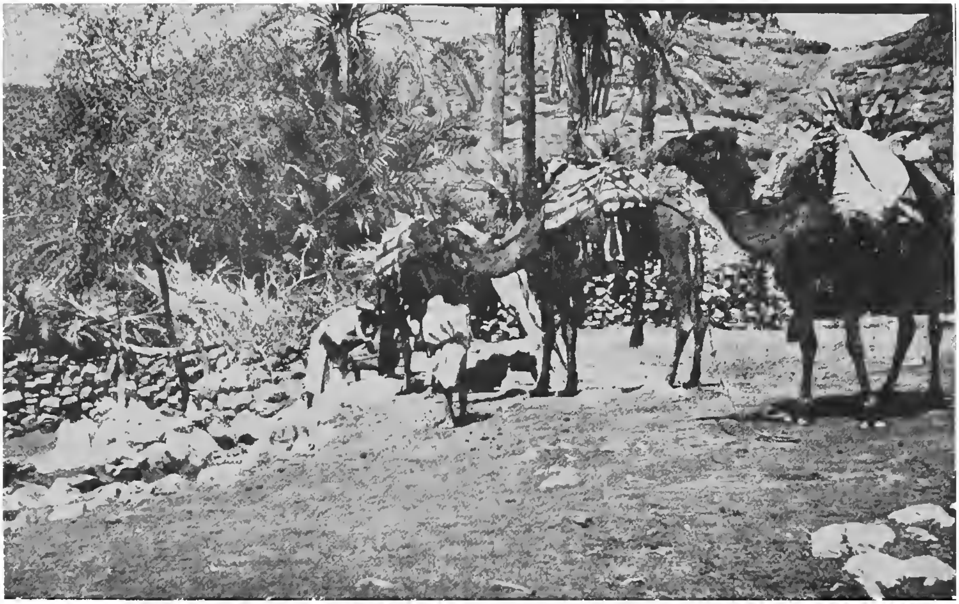
About a kilometre and a half below Bir Nasib there is an easy track into the short **Wadi Moerid,** which forms a slightly shorter route for a traveller between the well and Wadi Baba than by going up Wadi Nasib from its mouth.

Wadi el Dibabat is a broad and very sandy wadi which heads in the sands of Debbet el Qeri and courses due south for about three kilometres, to join Wadi Baba nearly opposite to the mouth of Wadi Moerid.

Wadi Um Themeiyim is a little wadi draining the hills between Gebel Hazbar and Wadi Baba ; coursing almost due eastward for about two kilometres, it joins Wadi Baba a little below Wadi Dibabat.

Wadi Um Thifeirat enters Wadi Baba from the south, nearly opposite to the foregoing ; its head lies on the western face of the high hills to the west of Bir Nasib, and it pursues a rather sinuous course of some four kilometres among lower hills before joining Baba.

Wadi Kharig, a rather important feeder of Wadi Baba from the north, originates in the sandy plain of Debbet el Qeri close west of Gebel Hazbar. The head is a great slope of drifted sand, which is easy enough to get down, but very tiring to get up, and on this



Camels watering at Bir Nasib.

Garden at Bir Nasib.

account the Arabs approaching the Debbet el Qeri from Baba prefer to go by the Wadi Dibabat. Passing the south point of Gebel Hazbar, Wadi Kharig receives a feeder from the eastern side of that hill, and then broadens out, with a flat floor and a fair number of trees. A large ancient mine (*see* page 190) is to be seen on the west side of the wadi in this part. A little below the mine Wadi Kharig is fed from the west by the little **Wadi Khrêg Hamda,** and then joins Baba on a small open plain. The total length of Wadi Kharig is about four and a half kilometres, and the fall from its head is 150 metres; the greater part of this fall is accomplished in the first kilometre or so, the lower portion having only a gentle slope.

Wadi el Banat, which joins Wadi Baba from the west near Bir Reḳîs, is formed by the union of a number of small wadis draining the hilly country immediately south of the Debbet el Qeri. Of these contributory wadis, only one, the **Wadi Um Biyerat,** bears a name, but two localities in a more northerly one are called **El Saqia** and **Seyal el Khâdim** respectively. El Saqia is marked by a date palm, while Seyal el Khâdim is a small plain with some very large seyal trees. A short way above where it opens out into Baba, Wadi el Banat drops over a precipice called **Sidd el Banat.** This prevents ascent of the wadi from its mouth, and the upper portions are best reached from Wadi Baba by a steep and winding track which leads from the head of Wadi Abu Maghara.

Wadi el Rekîs is the name given to the short stretch of valley, less than a kilometre in length, which conveys the combined drainages of Wadis Abu Thor, Abu Hamata, and Himeirâ,* to Wadi Baba at Bir Rekîs. All the three contributory wadis are steeply-falling stony gorges having their heads in the highly dissected plateau country lying between the Um Bogma mines and Wadi Nasib, and the upper parts of all three are shut in by scarps in which manganese ores abound at a certain horizon. Of the three wadis, **Wadi Abu Thor,** the most northerly, receives a small feeder called **Wadi el Thifeiria,** near the mouth of which there is a water source called **Bir el Thifeiria.** **Wadi Abu Hamata,** the longest, has springs of good water among palms near its head; these are called **Ain Abu Hamata.** The **Wadi**

* This same name Wadi Himeirâ, which means the "reddish wadi," is also applied to a number of other feeders of Wadis Baba and Shellal.

Himeirâ, which follows an almost northerly course, joins Wadi Abu Hamata a little above where the latter unites with Abu Thor. The scarps at the sides of all three wadis are quite formidable, and there is no passage for camels out of them except by retracing one's way to Wadi Baba.

Wadi Abu Maghara, which joins Baba a little below Bir Rekîs, **Wadi Filk,** which enters Baba at the place called El Zira'a, and **Wadi el Temmaria,** which joins Baba just below El Shârib, are all short drainage lines from the hills south-east of El Qôr. Wadi Filk commences as a fairly flat and open valley winding about among the hills at the eastern edge of the Qôr plateau before plunging over the edge into a deep rocky ravine. The other two are steep and stony throughout their course. There is a very steep and winding camel track leading up Wadi Abu Maghara, past some manganese mines at its head, and on to the heads of Wadi el Banat.

The **Wadi el Himeirâ,*** a deeply eroded rocky ravine which joins Baba from the south between El Aqaba and El Disa, collects the drainage from the north side of the plateau hills on which the Um Bogma mines are situated; a view of one of the heads of this wadi, looking from Um Bogma towards Baba, is shown on Plate IX, and gives a good idea of the canyon-like scenery of this part of the Baba basin. **Wadi Abu Themam,** entering Baba from the east a kilometre above the junction of Wadi Samrâ, is a similar deeply cut ravine draining from between two high plateau hills south of the ropeway.

Wadi Samrâ, which joins Wadi Baba from the north at a great bend some three and a half kilometres above the point where Baba emerges on to the coast plain, drains the south part of El Qôr plateau and the eastern faces of Gebel Samrâ. It is a narrow wadi, shut in by high mountains on either hand, and its heads are very steep (*see* the upper view on Plate X). The fall of its main channel is from about 500 metres above sea, where it drops over the plateau edge, to 150 metres at its junction with Baba, a drop of some 350 metres in a length of about six and a half kilometres, or over fifty metres per kilometre; and its lateral feeders are much steeper.

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* *See* footnote to p. 81.

PLATE IX.

View from near Um Bogma Mines, looking down one of the heads of Wadi Himeira towards Wadi Baba.

Wadi Shellal, the greatest of the tributaries of Baba, is quite of equal importance with Wadi Baba itself. It consists of two distinct parts, of which the lower one is a narrow winding rocky gorge shut in by high mountains; this is the Wadi Shellal proper, while the upper portion, which is more open and contains abundance of trees and bushes as well as several good water sources, is called **Wadi el Sâhu.** Till recently, though they form one and the same drainage line, Wadi el Sâhu was practically cut off from Wadi Shellal by the circumstance of a very steep drop in its rocky bed where the great gorge commences near Bir Abu Sibeikhat; this obstruction in the channel rendered it quite impossible for camels to ascend to the Sâhu from Wadi Shellal proper, and the only access to the verdant upper reaches was over the pass at the head of Wadi el Lahian. But lately the necessity of getting material up to the mines of Um Bogma has led the mining company to blast out a road through the obstruction, and now camels can pass right up Wadi Shellal and into the Sâhu.

Wadi el Sâhu originates by the union of the three wadis, Tilaʿgabir, Abu el Tiur, and El Féra, to the east of Gebel ʿAdeidia (near the south-east corner of the map on Plate I); the level of the wadi floor here is nearly 700 metres above the sea. **Wadi Tilaʿgabir** heads at a steep and stony pass, 765 metres above sea, practicable only for lightly loaded camels, leading into the head of Wadi Baba. It runs almost due south for three and a half kilometres to join el Sâhu, receiving several small feeders from the high hills on each side. Of these feeders, the principal is the **Wadi Zahloqa,** which enters from the east about two kilometres down from the pass. A few hundred metres up Wadi Zahloqa there is a steep track up a tributary gully to the south, leading to a pass nearly on a level with the upper part of the main wadi, here called **Wadi Siheiya**; the wadi floor here is fairly flat and sandy, with a good number of trees. **Wadi Abu el Tiur,** which forms the direct prolongation of Wadi el Sâhu, is quite short, being only about two kilometres long, while **Wadi el Féra,** which comes from due south opposite to Wadi Tilaʿgabir, is not much longer.

About a kilometre below the junction of the above-mentioned three wadis, Wadi el Sâhu receives a small feeder from the north face of Gebel ʿAdeidia, a little way up which feeder there is an easily accessible well, called **Bir el ʿAdeid.**

A little farther down its course, Wadi el Sâhu, which is here some 300 metres broad, receives from the south the **Wadi Um Retema,** which drains the steep western faces of Gebel ʿAdeidia. There is a steep road leading up the east side of Wadi Um Retema about two kilometres up from its mouth, and this road continues southward to near the head of the wadi on a high rocky ledge.

Wadi el Marahil, which joins Wadi el Sâhu further on, comes in from behind the semi-detached basalt-capped hill called Gebel Marahil. This wadi is important as leading to the pass into Wadi el Lahian, already referred to.

Wadi el Khâraza and **Wadi Rekeis,** which enters the Sâhu from the north near the white tomb of Sheikh Hashash, are steep and stony ravines draining the southern faces of Gebel Farsh el Azraq.

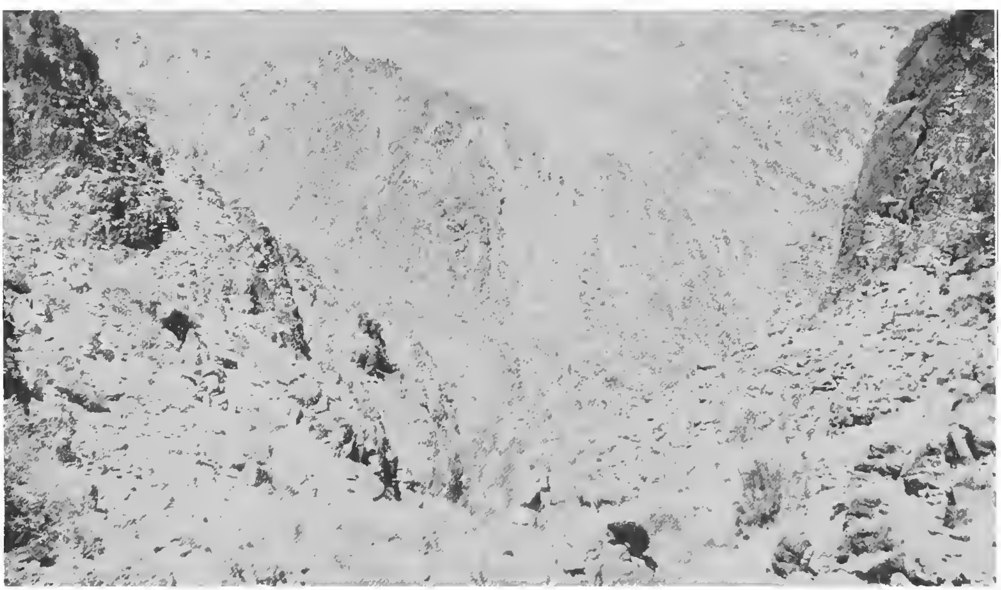
In the **Wadi Um Seyelat,** a very small feeder of El Sâhu from the south, there are some manganese workings.

Wadi Hasania, the next tributary of El Sâhu from the north, is quite a short drainage line with a very steep head, up which runs a zigzag camel road to the mines of Um Bogma. The pass at its head is 722 metres above sea, while at its junction with Wadi el Sâhu, only a kilometre and a half from its head, the level is 550 metres, a drop of 172 metres in this short distance. This road, which has been recently made by the miners, is practicable for camels not too heavily loaded, but the ascent with its forty or fifty turns is long and tiring for them ; another road, which will be mentioned further on as starting from Bir Abu Sibeikhat, is preferable and more direct.

Wadi Um Sakran, which drains southward into El Sâhu from the Um Bogma plateau, is a short and very steep ravine with mountains on either side.

Wadi Um Hamd, which joins Wadi el Sâhu from the south-east about half a kilometre below Wadi Um Sakran, is a very narrow stony valley, draining by numerous feeders the mountainous tract to the east of Gebel Moneiga. Its head, which is close to that of the Wadi Um Retema, and can be reached from that wadi by a steep tract, very difficult for even lightly loaded camels, is 840 metres above sea level. There is, however, no passage for camels down into Um Hamd itself at this point, the head being so steep that it is difficult of descent even on foot. About a kilometre and a half from its head, the channel opens out a little, though very stony, and here is a place called

Wadi Samra.



Head of Wadi Hezeimat.

El Hafira, marked by palms, but no well. El Hafira is 640 metres above sea, so that the fall of the wadi from its head is no less than 200 metres in a horizontal distance of one and a half kilometres, or over 130 metres per kilometre. About a kilometre below El Hafira, Wadi Um Hamd takes a sharp bend to the westward, winding about considerably and passing through a very narrow chasm before reaching **Bir Um Hamd,** a well amongst palms in the wadi bed, 535 metres above sea and about three kilometres below El Hafira. A further kilometre and a half of its winding course brings Wadi Um Hamd into Wadi el Sâhu.

Of the numerous feeders of Wadi Um Hamd, two only are of any considerable length. One of these, which appears to bear no name, follows a northerly course of about two and a half kilometres along the eastern foot of Gebel Abu Treifia, and joins Um Hamd about a kilometre above the well. The other, called **Wadi Abu Treifia,** heads at the very steep ridge which connects Gebel Moneiga with Gebel Abu Treifia, and coursing northwards along the eastern foot of Gebel Moneiga, enters Um Hamd a little below the well.

The short **Wadi el Hezeimat,** which drains the western faces of Gebel Moneiga and enters Wadi el Sâhu from the south, heads in a very steep pass which leads over into one of the feeders of another wadi, likewise called El Hezeimat, draining southwards into the Sidri basin. This pass is so narrow that there is only room to pitch one small tent on it, and so steep that it is only just possible to get camels over it, even animals used to mountains and carrying very light loads. A view looking down the northern Wadi el Hezeimat, from near the pass, is shown in the lower illustration on Plate X.

A kilometre further down its course than the point of influx of Wadi el Hezeimat, Wadi el Sâhu contains a well, called **Bir Abu Sibeikhat,** recently excavated in the rocky floor of the wadi. This well, which is 433 metres above sea-level, was yielding plenty of good water when I visited it on April 21, 1914; but I heard that the supply had given out a few days later, and I have not heard whether it has been renewed. A steep camel road, recently constructed by the engineers of the Sinai Mining Company, zigzags up the mountains northward from the well, which leads in about an hour and a half to the manganese mines of Um Bogma. Though this road is steep (the rise to the mines is about 300 metres), it is so well

made that loaded camels can get up without much difficulty, and until the ropeway is finished it forms the best route to the mines.

From Bir Abu Sibeikhat onwards, the Wadi el Sâhu becomes the Wadi Shellal, a magnificant narrow rocky gorge winding about among mountains for nearly ten kilometres before joining Wadi Baba. In this part of its course, the feeders of Wadi Shellal are **Wadi el Himeirâ,*** which drains the high plateau country to the north, and the **Wadi Abu Natash,** which courses westwards, draining an extensive mountain tract to the west of Gebel Moneiga. There are in addition numerous unnamed feeders from the surrounding mountains; they are all steep rocky ravines, and most of them join Wadi Shellal by dropping over precipices. The view on Plate XI, taken from the head of one of these ravines, will give a good idea of their wild character.

The **Naqb Budra,** a well known pass situated on the south side of Wadi Shellal, about four kilometres up from the junction of Shellal with Wadi Baba, is a steep zigzag track cut in the rock, leading out of Shellal into the **Wadi Budra,** a tributary of Wadi Sidri.

Wadi Sidri and its Tributaries.

Besides the Wadi Budra just referred to, the heads of a number of other feeders of Wadi Sidri are shown along the south border, and also along the lower part of the east border, of the map on Plate I. The further courses of these have not been mapped in detail, but the Wadi Sidri itself and its principal tributaries are shown on the Ordnance Maps of Sinai, by Captains Wilson and Palmer, issued by the Committee of the Palestine Exploration Fund, London, 1869, while numerous notes on these drainages will be found in Mr. Barron's "Geography and Geology of the Peninsula of Sinai (Western Portion)," issued by the Survey Department of Egypt in 1907.

The Plain of El Markhâ.

The plain of El Markhâ, supposed by some to be the "Wilderness of Sin" of the Israelites, is a stony plain with some scattered bushes, sloping gradually down to the sea, with an average width from east to west of about seven kilometres. Its northern limit is the parallel of 29° north, along which the hills near the sea end suddenly, and it

* *See* footnote on p. 81.

PLATE XI.

View from near the Um Bogma Mines, looking down one of the tributaries of Wadi Shellal.
(Gebel Serbal in the distance.)

extends for some twenty kilometres southwards, gradually narrowing towards its southern extremity. The name " Plain of El Markhâ," derived from the well at its northern end, though a convenient designation for it as a geographical unit, is not used by the Arabs ; the different parts of the plain are known by names derived from the drainages debouching on it, as **'Elwa el Markhâ**, **'Elwa Baba,** and so on. The surface of the plain consists of gravel, decreasing in coarseness as one approaches the sea. Near the coast it is easily traversable in all directions, but near the feet of the mountains progress is more tiring, partly on account of the more bouldery nature of the gravel and partly because of the shallow but steep-sided channels cut through it by occasional streams issuing from the mountains. The highest elevations on the plain are near the mouths of great wadis ; at the mouth of Wadi Baba, for instance, the level is 105 metres above the sea, and the form of the plain from this as centre is that of the half of a very flat cone, the ground falling at the rate of about twelve metres per kilometre in all directions through a horizontal angle of 180°. Where the debouching wadis are short and steep, as for instance at the mouth of Wadi Dafari, the level of the edge of the plain is lower and the drainage lines cut through the alluvial deposits in ruts.

The Plain of Debbet el Qeri.*

The Debbet el Qeri is a great sandy plain which extends from the Wadi el Hommur to the heads of Wadi Khaboba and the various southward coursing tributaries of Wadi Baba. It derives its name from its sandy character (*debbet* = sand) and from the circumstance that on it is situated (near Gebel Hazbar) the tomb of a sheikh called Qeri. Geographically, the most striking feature about this plain is its gradual rise to the south, due to the prevalent northerly winds carrying the sand along and heaping it up to heights of over 500 metres above sea with a gradual overflow into the heads of the deeply cut wadis draining southwards. Figure 7, which shows a section from north to south across the plain, exhibits this feature, and there can be no doubt that the present tendency of the sand is to move southwards and

* This plain has frequently been erroneously marked on maps as the " Debbet el Ramla." Both "Debbet" and "Ramla" mean the same thing, namely, *sand*. An Arab speaks of the place indifferently as "Debbet" or "El Ramla," but never uses the two names together, which would be a similar thing to speaking of " Lake Nyanza."

choke the heads of the wadis. Though the sand, being wind drifted, is of the same character as that which forms impassable dunes in the western deserts of Egypt, the Debbet el Qeri is only difficult for camels

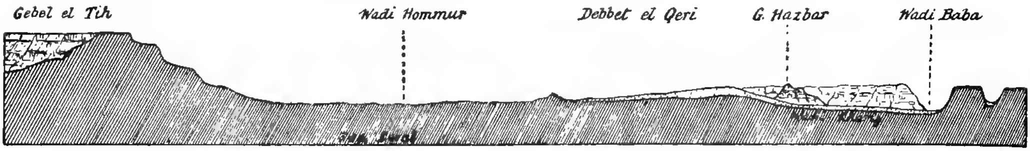


FIG. 7.—Section from Gebel el Tih southwards across the Debbet el Qeri. (The vertical scale is the same as the horizontal.)

in a few places, being covered with scattered bushes, the roots of which hold it together and give a fairly firm surface. In fact, the vegetation is so abundant that for a year or two after a good rainfall the plain forms good grazing ground for sheep and goats. Its fairly level surface, combined with the visibility from it of prominent points on the scarp of El Tih and on the mountains to the south, led to the Debbet el Qeri being chosen for the base line of my triangulation. Needless to say, though pleasant enough in winter, the passage across the Debbet el Qeri is very tiring on a hot still day in spring or summer, owing to the intense heat of the sand.

Elevated Plains.

With the exception of the plain of El Markhâ and the Debbet el Qeri above described, this part of Sinai is practically all mountainous. There are, however, two places where the mountain tops are fairly flat over small areas, and where in years of heavy rainfall small tracts have been cultivated. These are **Mezra el Qôr**, described on page 74, and **Mezra Abu ʿAlfa**, a small sandstone plateau 840 metres above sea-level, to the west of the pass at the head of Wadi Baʿla. At neither of these places, however, was there any cultivated ground in 1914, a succession of dry years having elapsed since the last considerable rainfall.

CHAPTER IV.

MOUNTAINS AND HILLS.

In this chapter will be given a description of the principal mountains and hills in the mapped district, commencing with Gebel el Tih in the north and taking the remainder in order from north to south.

Gebel el Tih is not the name of a mountain, but of a great tract of high-lying country which ends in a bold escarpment over 500 metres high, facing to the south. This escarpment extends in an irregular line for some two-thirds of the way across the peninsula about latitude 29° 10′; only a portion of it thus comes within the surveyed district. As viewed by a traveller passing along the sandy plain to the south, the impression given is that Gebel el Tih is a flat limestone plateau. But the impression is quickly dispelled when one has made the toilsome ascent of the scarp, for in place of the flat plateau which one would naturally expect, one finds that from the very edge of the scarp there commence deeply eroded wadis draining northward, descent into which is almost equally steep with that of the scarp to the south. Gebel el Tih is in truth a dissected plateau, but the dissection is so intense that to any one except the student of land forms it is more naturally described as an assemblage of mountains having more or less of a plateau structure, connected together at their southern extremities to form a nearly continuous scarp, but separated to the north by deep ravines. As will be seen from the map, the various mountains thus united bear special names, Gebel Ras el Hemeitia, Gebel Ras Um Qatafa, Gebel Shushet Abu el Nimran, Gebel Ras Watâ, Gebel Sâlia, and Gebel Rueikna being all constituent parts of Gebel el Tih, while Gebels Abu ʿEdeimat and ʿIseila are really semi-detached parts of the same mass.

The highest point of the portion of Gebel el Tih within the mapped area is Gebel Sâlia, with an altitude of 1,189 metres. But this altitude is far surpassed further east and north-east, for Gebel Raqaba, a prominent corner of the scarp, surmounted by a triangulation beacon, in latitude 29° 7′ 30·5″, longitude 33° 2′ 19·7″, was found to reach 1,403 metres, and several points triangulated further to the north-

east, forming parts of a second escarpment north of the main one, attain to over 1,600 metres. These altitudes, found by careful trigonometric levelling, came as a great surprise, for it had not hitherto been suspected that Gebel el Tih might be almost equally high with the much more prominent Red Sea ranges of Egypt.

The southward facing escarpment of El Tih is very formidable, rising to an average height of about 600 metres above the plain at its foot. The lowest two-thirds of the face consist of thick beds of reddish and brownish sandstones, while the uppermost third is mostly of white limestone and greenish clays. The uppermost sandstone beds, immediately below the limestones, usually form a sort of flanking platform round the scarp, with a precipitous drop of a hundred metres or more, above which the limestones and clays present a less steep slope, though here too the harder limestone beds have often vertical faces. In the eastern part of the scarp there is a thick bed of basalt intercalated near the top of the sandstone, and this likewise usually presents a precipitous face. So steep is the scarp, that a skilled climber has to chose his place carefully for an ascent on foot, and the places where camels can get up are very few indeed.

After commencing the survey by measuring the base line on the sandy plain of Debbet el Qeri, my first move was naturally to ascend the escarpment of El Tih, in order to extend the triangulation from stations at commanding altitudes on its top. My Arab guides reported that the least difficult road for camels up the scarp was by a track called **El Rakna**, which ascends in about longitude 33° 30′; but finding this to lie some distance east of the limits within which I had perforce to keep the map, I decided to ascend by a rather more difficult track called **El Rueikna** (a diminutive from El Rakna), which lies a little further west and consequently comes within the limits of the map. This track is the one marked "bad camel road" on Plate I. Crossing the sandy plain from our base line camp near Abu Rodeiyim, we arrived with our full equipment at our fourth camp at the foot of Gebel el Sâlia, but as the guides reported the ascent to be extremely difficult, the caravan was here divided into two parts, one to consist of selected climbing camels, lightly loaded with necessaries, to ascend the scarp and move along its top westwards, the other with the heavier gear and reserve stores to move correspondingly along the foot of the mountains. It took us only two and a half hours of easy climbing

to go on foot round the east side of Gebel el Sâlia and thence up to its summit, but the baggage camels, lightly laden though they were, consumed six and a half hours in the ascent, owing to the very steep road with its many windings; indeed, the road is so bad that the Arabs performed quite a feat in getting the animals up at all, but they were encouraged by the hope, fully justified, of finding good camel food on the top. The triangulation beacon which marks the summit of **Gebel el Sâlia** is in latitude 29° 11′ 16·7″, longitude 33° 25′ 27·8″, and is 1,189 metres above sea-level and 574 metres above our camp at its foot. The view from the top in clear weather is very extensive. All the great mountains of the south part of the peninsula, including Gebels Serbal and Um Shomer, stand out clearly, while across the Gulf of Suez, Gebel Gharib is well seen and the light-houses of Zafarana and Ras Gharib, respectively 74 and 98 kilometres distant, can be seen at night. To the north, the view is less extensive owing to the plateau structure of the hills, but an upper scarp of white rocks, rising to heights of over 1,600 metres above sea, is very prominent in the morning light. The lower country at the foot of the scarp lies spread out like a map, and grand views of the great scarp are seen on either hand. Two views looking along the escarpment are shown on Plate XII.

Once one has mounted the escarpment, there is no great difficulty in moving about along it, but the top is far from level, and its surface is very stony, so that camel-men require some time to find their way about without damaging their animals. Exposed to the cutting north winds in winter, the place is extremely cold; but luckily there are plenty of bushes and fires can be made with very little trouble in collecting material. These same bushes give abundance of camel food, and Arabs will stand any amount of personal inconvenience if only their camels can feed at a place.

From Gebel el Sâlia we journeyed westwards along near the edge of the scarp, surveying the country below us by triangulating hundreds of points from short bases, over the part called Gebel Ras Watâ, on to **Gebel Shushet Abu el Nimran.** The approach to this prominent point of El Tih along the top is rather difficult, mainly owing to the deep in-cutting of northward draining wadis which extend right up to the scarp. If one goes on foot, there is no very difficult climbing, but camels have to skirt the precipitous heads

of the Wadi Abu el Nimran and go north-westwards right round the summit, the nearest practicable place for a camp being half a kilometre south-west of the beacon. The triangulation beacon on the summit of Gebel Shushet Abu el Nimran is in latitude 27 11′ 21·9″, longitude 33° 18′ 31·9″, at an altitude of 1,102 metres above the sea. Gebel Shushet Abu el Nimran, though eighty-seven metres lower than Gebel Sâlia, is, if anything, rather a finer outlook station, owing to its being on a sort of promontory of the scarp. Much of the upper plateau is no longer visible, but all the mountains in the southern part of the peninsula, as well as those on the Egyptian side of the Gulf of Suez, south of Wadi Araba, are well seen, while in addition the beacon on Gebel Hammam Faraûn, thirty-three kilometres to the west, is just visible from it over the intervening plateau by pitching one's theodolite tripod a little higher than usual.

Between Shushet Abu el Nimran and Gebel Ras Um Qatafa, the next triangulation station westward, the top of the Tih scarp is pretty rough going, being broken up by the heads of the deeply eroded Wadi Um Dûd. About half-way between the two points is a white peak, called Ras Deneib Agrab, which, though only 989 metres above sea, is very conspicuous owing to its being close to the edge of the scarp; there is said to be a steep track up the scarp hereabouts, though I did not see it.

From **Gebel Ras Um Qatafa,** a conical eminence surmounted by a triangulation beacon, rising from the plateau in latitude 29° 11′ 40·9″, longitude 33° 16′ 33·4″, 1,054 metres above sea, I managed to get theodolite sights at night, not only on to Gharib and Zafarana lighthouses, but also on to that of Newport Rock, Suez Bay, the last named being fortunately visible through a gap in the hills, though its distance from the station is 104 kilometres.

From Gebel Ras Um Qatafa, we journeyed north-westwards, surveying along the edge of the scarp to **Gebel Ras el Hemeitia,** a ridge rising to 910 metres above sea at the face of the plateau in latitude 29° 15′. The most conspicuous feature in this stretch of the scarp is the presence of a persistent bed of sandstone, at the base of the Turonian strata, about eight metres thick, forming a steep upper ledge at the face, while about half-way down is another lower ledge due to the outcrop of the much thicker Nubian sandstone. There is a gradual fall in the plateau level north-westwards, the upper

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ledge of the scarp close to Gebel Ras el Hemeitia having an altitude of about 800 metres above sea, against 960 metres close to Gebel Ras Um Qatafa. Close to Gebel Ras el Hemeitia the deeply cut heads of Wadi Hemeitia descend north-westward, and there is a steep track winding westward down the main scarp, which we followed to reach our tenth camp at the head of Wadi el 'Iseila; this track, which drops 220 metres in a distance of a kilometre and a half, is very rough, and practicable only for lightly loaded camels. **Gebel el Ratama,** a conspicuous peak 891 metres above sea-level, close to the edge of the scarp in latitude 29° 15′ 38″, longitude 33° 11′ 48″, lies about a kilometre and a half north-west of the place where the track descends.

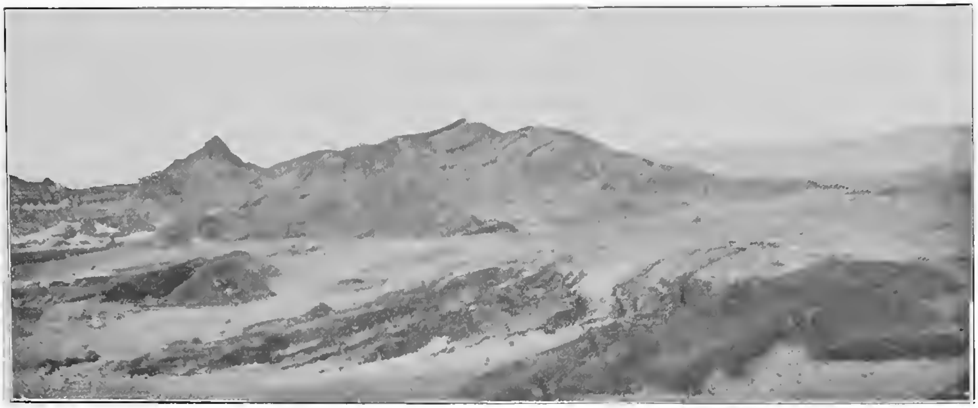
Gebel Abu 'Edeimat may be regarded as a semi-detached portion of the Tih plateau, being connected with Gebel Ras el Hemeitia by a little group of white hills separating the head of Wadi Thal from that of Wadi el 'Iseila. Gebel Abu 'Edeimat is a highly dissected plateau, sloping gently north-westwards, covering about ten square kilometres. The triangulation beacon, on one of its highest points near the south end of the mass, is in latitude 29° 12′ 7·3″, longitude 33° 11′ 7·1″, and 799 metres above sea-level. The faces of the plateau, and the sides of the numerous deeply eroded wadis which cut into it, are very steep and of the same general character as the corresponding features of the Tih escarpment. The heart of the mass is drained northward by tributaries of Wadi Thal, while the drainage from the west, south, and east faces passes into Wadi Teyiba. The ascent of the mountain is best undertaken from the head of Wadi el 'Iseila, where the ground level is about 580 metres; from this point I found it possible to get lightly loaded camels to the top of the plateau, and thence by a devious course, rounding the heads of the wadis, to the triangulation point. The top of the plateau, especially near its high western edge, is very rough ground of broken limestone. On my way to the beacon, I came across a curious cavity in the limestone of a ridge rising from the general plateau level; a sort of pit, nearly full of great lumps of limestone, very moist and *warm.* The Arabs could not explain what this was, but suggested it had been made by a thunderbolt; I tried to remove the stones which encumbered the hole, to get a look at the bottom, but I found them too large to move without crowbars or similar tackle, and did not find any explanation. There may be a tiny hot spring at the place, but it is difficult to account for the local breaking up of the rock.

Gebel el ʿIseila is a great ridge of limestone rocks tilted strongly to the east, running for some five kilometres in a north and south direction to the east of Gebel Abu ʿEdeimat. Its highest point, near its south end, is 650 metres above sea. The eastern and western faces of the ridge are drained by Wadi Abu Insakar and Wadi el ʿIseila respectively.

Gebel Gorlos and **Gebel el Tihia** are two rather low but very conspicuous hill masses of white chalk, lying one on either side of Wadi el ʿIseila just above where the latter joins Wadi Abu Insakar. Their eastern faces are extremely steep, but ascent from the western faces, along the dip slope of the rocks, is easy enough. Gebel Gorlos reaches 412 metres, and Gebel el Tihia 390 metres, above sea ; the wadi level between them is 260 metres.

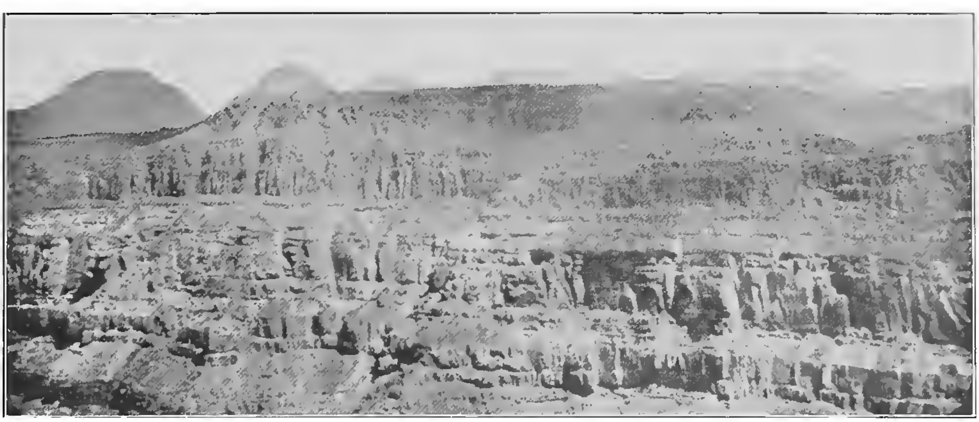
Gebel Sarbut el Gamal is a great hill mass of limestone and conglomerate, situated on the north side of Wadi Teyiba. The triangulation cairn on its highest point is in latitude 29° 8′ 15″·6, longitude 33° 12′ 51″·1, and is 642 metres above sea-level. Sarbut el Gamal is a good landmark to travellers in the Wadi Teyiba and on the Debbet el Qeri, being visible from considerable distances in an east-and-west direction. The mass is cut nearly in two parts by a hanging wadi (mentioned on page 70). I ascended the western part, as although this is about 100 metres lower than the eastern one on which the cairn stands, it gives a better view of the flanking hills to the west. The climb from the central wadi is steep but not difficult ; the higher part to the east rises more abruptly and its eastern face is precipitous.

Gebel Musabaʿ Salâma, another great hill mass on the opposite side of Wadi Teyiba, is likewise a good landmark. Its summit is quite sharp, and bears a triangulation cairn in latitude 29° 6′ 20″·3, longitude 33° 14′ 8″·6, 583 metres above sea-level. On the western side are high flanking hills, but on the south-east there is a small plain tract close to its foot, 365 metres above sea ; the climb to the summit is best made from this plain, and can be accomplished in about half an hour. The hill mass of Musabaʿ Salâma is extremely interesting to the geologist, for owing to its being on a fault, a great range of formations is exposed, and tilting and curving of the strata are well displayed ; this will be evident from the uppermost view on Plate XIII, which is taken from the south side of the mass.



Gebel Musabaʿ Salâma, from the south-east.

Gebel Farsh el Azraq.



Another view of Gebel Farsh el Azraq.
(Basalt overlying Carboniferous sandstone.)

Gebel Matulla is a range of white hills, mostly composed of chalky rocks, the crest of which runs in a nearly north-and-south direction for several kilometres near the meridian of 33° 10′. The eastern slopes of this range, draining to the Wadi Khaboba, are extremely steep; but to the west there is a more gradual descent, the mass being much cut up by the various heads of Wadi Matulla. The highest point, 421 metres above sea-level, is marked by a triangulation cairn in latitude 29° 5′ 4″·4, longitude 33° 9′ 51″·3. There are several more triangulation points further along the range, the most conspicuous being the one at the south end, where the range terminates in a great precipice; the cairn on this end point is 398 metres above sea in latitude 29° 2′ 45″·8, longitude 33° 9′ 43″·4. Ascent of the range from the east is very difficult except by the pass a little south of latitude 29° 5′. Even when one is on the crest the movement along it requires great care in many places, owing to the narrowness of the ridge and its being frequently broken by very steep-sided notches. The name of the range, Matulla, means "a place whence you look steeply down."

East of Gebel Matulla, between that range and Gebel Nukhul, is a great tract of white hill-country, over 100 square kilometres in extent, mostly drained by the Wadi Nukhul. The hills of this tract, some of which rise to over 400 metres above sea, bear no special names. They are mostly composed of tilted beds of chalky limestone, forming long ridge-summits with a very steep face to one side and a more gradual fall on the other, separated by more or less parallel wadis. The map on Plate I will give a better idea of the form of this complicated region than any description. Possible tracks across it are few in number. The Wadi Nukhul takes one right through the tract, and there is also a track, shown on the map, from the Wadi Nukhul to near Bir el Markhâ.

Gebel Nukhul is a high plateau with very irregular outline, very rough surface, and very steep sides, almost inaccessible to camels and at most points difficult of ascent even on foot. A cairn on its highest point, in latitude 29° 2′ 35″·2, longitude 33° 15′ 49″·9, 674 metres above sea-level, marks an important triangulation point, visible from great distances to the east and south, but hidden by the extension of the plateau to an observer from the west. The best way to reach the mountain with camels from the coast is a very roundabout

one; you go up Wadi Teyiba till you reach the western edge of the plain of Debbet el Qeri, then strike south to the Wadi Um Silla, follow this up to the broken plateau of El Qôr, across which latter you go eastward to Gebel Nukhul. At the narrow neck which connects Gebel Nukhul with the plateau of El Qôr (*see* map on Plate I), my men made a track, steep and difficult for camels, by which I was able to place a camp about a kilometre south-east of the cairn and about a hundred metres below it; camels could not approach nearer owing to the dissected nature of the plateau, and it required a good half-hour on foot, with some steep little climbs, to reach the cairn. The top of the plateau is quite hilly, and very rough and tiring to walk over, owing to the treacherous nature of the Upper Carboniferous sandstone, which is smashed up by the effects of faulting. The sides of the plateau are mostly great precipices, the edges of the thick Carboniferous limestone beds forming vertical walls, with sandstones, often scarcely less steep, and a footing of rugged granite below.

Gebel Samrâ is a double-peaked mountain of granite, overlooking the north part of the coast plain of El Markhâ. Its highest peak, 695 metres above sea-level, bears a cap of reddish sandstone, and is surmounted by a cairn in latitude 28° 59′ 19″·6, longitude 33° 16′ 13″·3. The two highest peaks form the centre of a rugged mountain mass, draining by very steep and stony ravines eastward to Wadi Samrâ, and westwards to Wadi Dafari. Gebel Samrâ is difficult of close approach with camels. To occupy it as a triangulation station, I approached it by way of Wadi Dafari, from which we reached the station by a long and tiring climb on foot up the ravines. The sandstone cap, about eighty metres thick, is very awkward to get up, the faces of the thick beds being very steep, while the weathering of the rock has made it hollow and treacherous. The upper photograph on Plate X, taken during our descent, will show the rugged nature of the approaches to the station. From the summit it is not possible to overlook well the immediately surrounding country, owing to the flanking peaks and ridges, and some laborious tramps and climbs had to be undertaken before the mapping of it could be accomplished; but a very good view is obtained of the complex geological jumble to the south, produced by the numerous faults which cross the Wadi Baba.

To the south-east of Gebel Samrâ there lies a tract of rugged mountainous country through which the Wadis Baba and Shellal pursue their courses to the sea in deeply cut gorges. None of these mountains bear special names. Some of them have caps of sandstone and limestone above the granitic rocks which form the main mass, an example being the mountains between Wadis Baba and Shellal, where the mines of Um Bogma are situated. They are all characterized by a steep and stony nature, being intersected by deeply cut ravines draining into the major wadis, only traversable on foot with great fatigue and expenditure of shoe-leather. The map (Plate I) will give more information than any detailed description of this tract.

Gebel Moneiga is a rather imposing mountain situated on the south side of the Wadi el Sâhu, close to the point where the wadi narrows in to form Wadi Shellal. It towers to over 600 metres above the wadi floor, its highest point, marked by a cairn in latitude 28° 57′ 13″·1, longitude 33° 21′ 58″·2, being 949 metres above sea-level. The lower portion of the mass is granite, with sandstones and a bed of intercalated limestone rising terrace-like above. The name Moneiga is said by the Arabs to mean "a place of lifting up of the hands," tending to suggest that here we have a possible identification of the mountain of the law. But though the Wadi Sâhu is fairly wide hereabouts, there hardly appears room for the great concourse of Israel, and as another (much higher) mountain in Sinai is likewise called Moneiga,* I am inclined to think the name has here no reference to Mosaic history. I did not climb to the top of the mountain, because, being flanked by extensive terraces, the mapping of its shape was much better accomplished from the terraces themselves; and even these were found very steep and dangerous in places. At one time I thought the ascent would have to be made, in order to settle the nature of the rock on the summit, which looks quite black, suggestive of basalt; but a telescopic sight under favourable illumination showed very distinct "ripple mark" in the black rock, which is thus surely iron-stained sandstone, such as one finds elsewhere in the district at this horizon.

Gebel Abu Treifia, a higher mountain to the south of Gebel Moneiga, attains 1,024 metres above sea; it is capped by a bed of basalt.

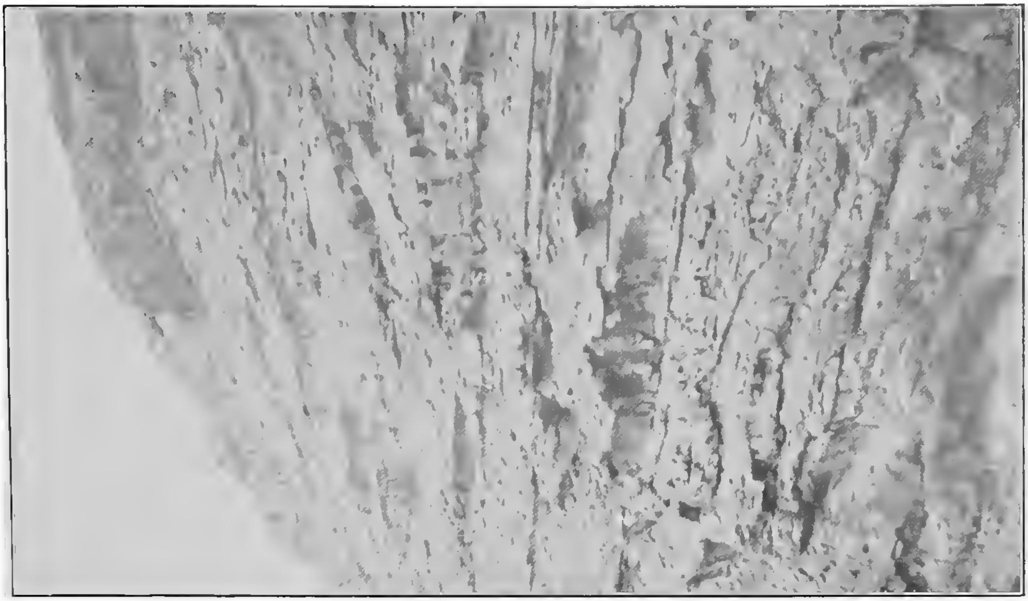
* BARRON, "Western Sinai," pp. 59, 66.

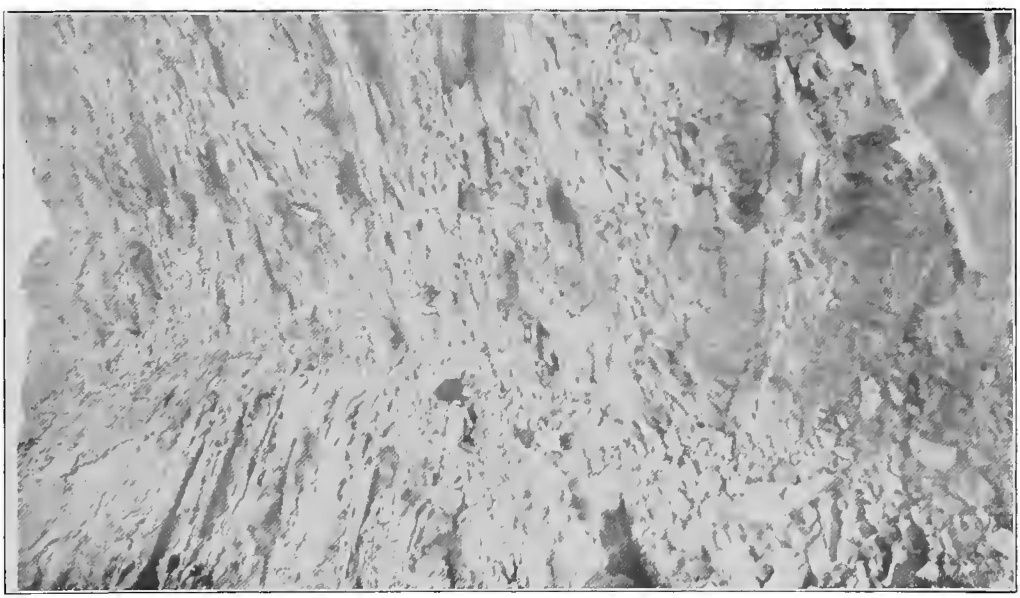
Gebel Farsh el Azraq, a high dissected plateau on the north side of the Wadi el Sâhu, some five kilometres north-east of Gebel Moneiga, derives its name "the black bed" from the circumstance that it is capped by a thick bed of black basalt. The top of the plateau, 890 metres above sea-level, is very rough to walk over, owing to the abundant shallow but steep sided gullies by which the surface is cut up, and the faces of the mass are extremely steep. A good idea of the structure of Gebel Farsh el Azraq is given by the two lower views on Plate XIII. I managed to get a camp on the top of the mountain by making a camel track, steep and difficult in places, from Wadi el Lahian. There is also a rough footpath, impracticable for camels, from the Wadi Sâhu, leading up the spur close north of the tomb of Sheikh Hashash.

Deleidim is a conspicuous conical hill, capped by basalt, a kilometre or so to the north of Farsh el Azraq. Its top is 787 metres above sea-level.

Gebel Marahil is a detached portion of Farsh el Azraq, from which it is separated by the Wadi Marahil. It is a high hill with a basalt cap; as one approaches it up the Wadi Sâhu, it looks quite detached from the neighbouring hills, but it is really joined on to them at its eastern end. Gebel Marahil forms a good landmark for the camel road which leads from the Wadi Sâhu up Wadi Marahil, and over a pass into the head of Wadi el Lahian.

Gebel Um Riglein, the most conspicuous mountain in this part of Sinai, culminates in two great peaks about 600 metres apart, rising abruptly from a slightly spreading sandstone platform resting on a granite base. The south-east peak is the higher and sharper of the two, reaching to 1,037 metres above sea-level. The north-west peak, 1,017 metres above sea, bears a triangulation cairn; the position of this cairn is latitude 29° 0′ 38″·8, longitude 33° 25′ 48″·9. Both the peaks of Um Riglein are extremely steep, presenting nearly vertical walls of sandstone; Mr. Murray, who erected the cairn on the north-west peak, climbed it from the north-west buttress in an hour and a half, and found the view well worth the exertion. The south-east peak looks more difficult. To the north of Um Riglein a long narrow tongue of sandstone plateau forming an extension of the platform from which the two peaks rise, stretches for about five kilometres as a cap along the granite mountain ridge which separates Wadi Lahian





Two views of the face of Gebel Sarabit el Khadim (sandstone).

from Wadi Baba; while a similiar but broader and shorter extension of the sandstone southwards forms the plateau on which Mezra Abu 'Alfa is situated.

Gebel Sarabit el Khâdim is an extensive rugged mountain mass to the east of Wadi Baba. Its highest parts, which are capped by basalt, are nearly on the parallel of 29°, the triangulation cairn on the summit being in latitude 29° 0′ 4″·4, longitude 33° 27′ 10″·6, and 1,096 metres above sea-level. Northwards from the highest point, the mass extends as a very broken sandstone plateau, cut up by numerous deep and steep-walled ravines; it is on this portion that the ruined temple is situated (*see* page 12). To the south, the range extends for a kilometre or so as a high precipitous ridge. I ascended Gebel Sarabit el Khâdim at two places. The first ascent, made in order to map the temple and its surroundings, was from the little Wadi Um Themeiyim, a tributary of Wadi Baba, and the top of the plateau here was reached by a steep climb; one of the views on Plate XIV shows the porters ascending with the surveying instruments, while the other shows the nearly vertical face by which we descended into the Wadi Baba again a few kilometres further north. The second ascent, on to the high south ridge, was undertaken in order to see what was on the other side; the ridge looked like a plateau from the west, but when, after a very steep climb, we reached the top, we found it only about a metre wide, with a huge drop on the east into the head of one of the feeders of Wadi Sidri.

Gebel 'Adeidia is a high mountain group situated on the south side of the Wadi Sâhu, near the meridian of 33° 25′. It consists mostly of sandstone; the edges of the beds form vertical walls, which in places are several hundred metres high. The highest point of the group, at the south end, rises to 1,044 metres above sea, and is marked by a triangulation cairn in latitude 28° 57′ 1″·6, longitude 33° 25′ 38″·7; there is also a cairn on the northern peak, which is much more conspicuous from the north, in latitude 28° 57′ 43″·4, longitude 33° 25′ 19″·1, and 994 metres above sea-level.

Gebel Hazbar, 576 metres above sea, forms a good landmark for travellers crossing the sandy plain of Debbet el Qeri.

Gebel Um Rinna, a hill-mass on the north side of Wadi el Sih, is important as containing deposits of manganese ore (*see* p. 188). The approaches to Um Rinna are mentioned on p. 78.

CHAPTER V.

NOTES ON THE COUNTRY BETWEEN ABU ZENIMA AND SUEZ.

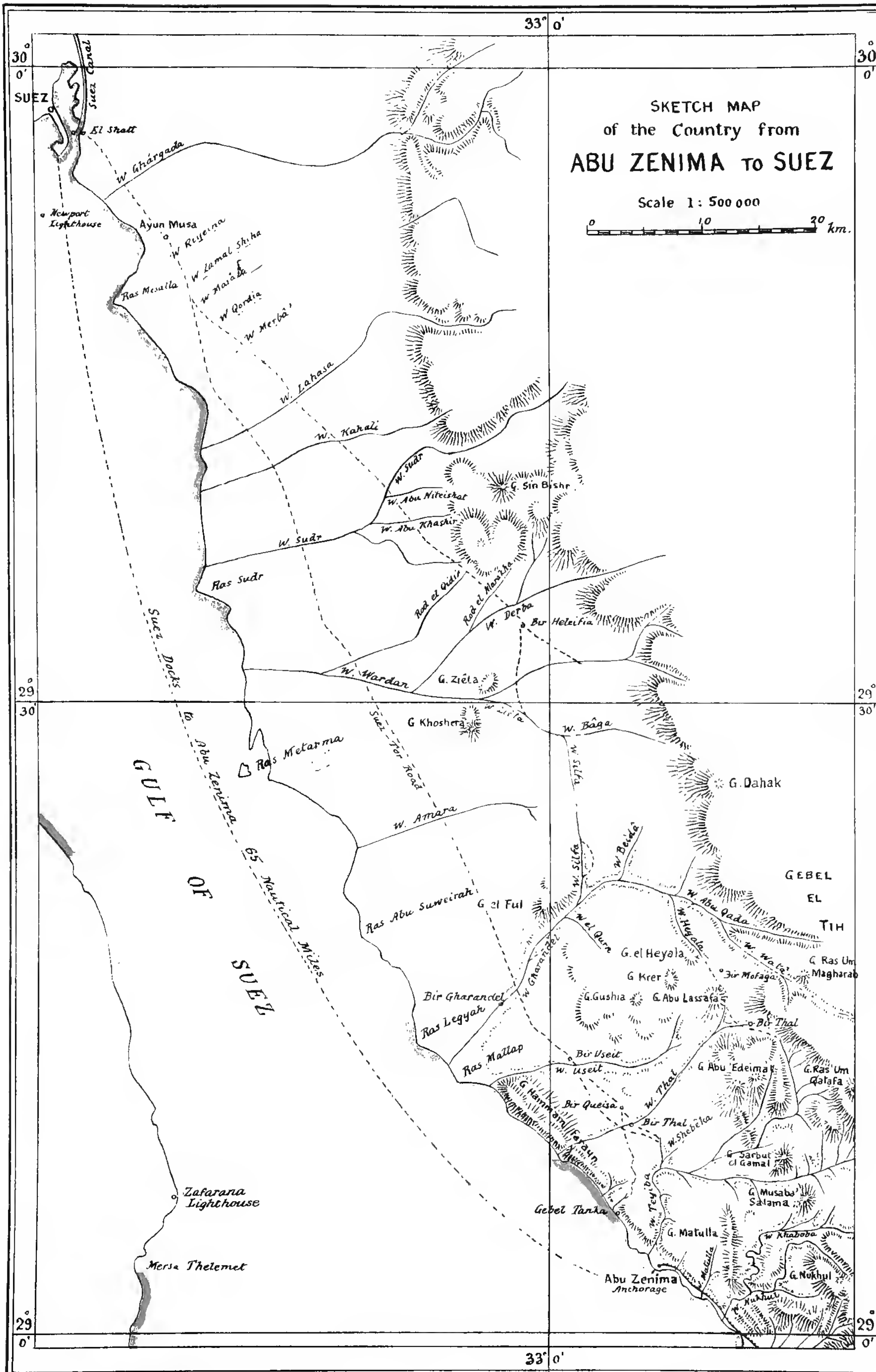
Though the detail mapping was confined to the area shown on Plate I, to which area the geographical descriptions in the two preceding chapters refer, the survey operations included a number of minor expeditions in the country to the west and north. On these expeditions, which were undertaken partly in order to occupy outlying triangulation stations and partly to examine interesting geological exposures, careful reconnaissance notes were taken. The geographical portion of these notes is given in the present chapter. The small scale sketch map on Plate XV will enable the description to be more easily followed. The geological notes taken at the same time are incorporated in the geological chapters.

Gebel Tanka and its Environs.

Gebel Tanka* is the westernmost part of a tract of low hills abutting on the coast in latitude 29° 5′. It derives its importance from the circumstance that borings for oil have recently been undertaken there by the Sinai Petroleum Syndicate. The hills terminate in a scarp some seventy metres high, so close to the coast that its foot is washed by the sea, and there is only room for a narrow road along the shore. This scarp extends for a distance of about a kilometre along the coast from north to south, and the oil wells are situated at its foot. At its south end, the scarp steps back slightly and breaks up into hills, and from here a rather wider stretch of plain extends for some six kilometres southwards to the Abu Zenima anchorage. Between Gebel Tanka and Abu Zenima, Wadi Teyiba emerges from the hills,

* This name is a modern one, probably derived from the English word *tank*, and doubtless refers to the water tanks used by the oil-drillers recently working here. As there is no true Arabic name for the place, it is conveniently retained.

PLATE XV.



Survey Dept. Cairo, 1915 (6930-50)

its mouth being marked by dark basaltic rocks which stand out very sharply among the surrounding limestones. Wadi Teyiba is important as forming an easy route into the interior of the peninsula, and has been thought by some to be the way by which the Israelites travelled. The hills immediately inland from Gebel Tanka have not been mapped, though triangulation points have been fixed on the more prominent ones, and sufficient fossils have been collected to establish the presence of both Eocene and Miocene rocks in them ; they are of no great height, but extremely complicated both topographically and geologically, on account of the highly dissected and faulted nature of the country. On the shore at Abu Zenima are the offices and loading plant of the Sinai Mining Company, who are exploiting the manganese deposits of Um Bogma, and a railway line has been constructed from Abu Zenima to the terminus of the cable road at El Mereighat.

Reconnaissance from the Head of Wadi Thal to the Hydrocarbon-bearing District near Wadi Abu Qâda.

The steep and stony track which leads down Wadi Thal from its head keeps at first on the north side of the wadi, but crosses to the south side about a kilometre above Bir Qattar (*see* the north-west corner of the map on Plate I), and then continues over spurs of rock and stony wadi bed to about half a kilometre below Bir Thal,* near where the sandstone boundary crosses the wadi. At this point the track turns off to the north, round a spur of the hills, into Wadi Lughb, where there are high banks of gravel, and then proceeds for some five kilometres, partly along the wadi bed, and partly skirting its west side, up to a pass, close east of the highest peak of the great ridge of Gebel Abu Lassaf, which leads from the head of Wadi Lughb into that of Wadi Mohfaqa ; the pass is about 520 metres above sea-level. After descending Wadi Mohfaqa for about a kilometre, a branch track leads off to the right, over low ridges and gullies, for about a kilometre and a half to **Bir Mohfaqa,** a well of good water in a rubble pitched excavation. The supply here is said to be perennial. Unlike most Sinai wells, Bir Mohfaqa is not marked by palms.

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* For notes on the upper part of Wadi Thal and the wells, *see* p. 68.

Aneroid readings gave the approximate altitude of the well as 455 metres above sea.

From Bir Mohfaqa, a track leads for about three kilometres down Wadi Kihelia, where there are numerous low walled enclosures and signs of ploughing, showing that certain areas are cultivated after rains, and passes close to the eastern foot of a hill range called **Gebel el Heyala**. At this point there is a pass, 455 metres above sea-level, from which the track falls steeply down the head of **Wadi el Heyala**, among clays and limestones. After following the course of Wadi el Heyala for some five kilometres, the track turns over the hills to the right for about two kilometres to reach the Wadi Abu Qâda. Along this part of the track, black chert-beds are conspicuous in the limestones and sandstones.

The **Wadi Abu Qâda** is a broad westward-coursing valley with a sandy and gravelly floor and abundance of bushes. The Suez-Nakhl road runs up it. The point where the tracks join is about 275 metres above sea-level. After going up Wadi Abu Qâda for about three kilometres, a number of trees are seen on the north side of the wadi; from here a side track leads for about a kilometre and a half to **Bir el Barazi**, which is said to yield a perennial supply of very good water. About half a kilometre further up, **Wadi Abu Qâda** is joined from the south by Wadi Watâ, a great drainage channel heading near Gebel Shushet Abu el Nimran; the point of junction of the two wadis is about 320 metres above sea.

From the junction point of the Wadis Abu Qâda and Watâ one may proceed up either Wadi. By following Wadi Abu Qâda for a few kilometres (*see* sketch map on page 140) one can reach the exposures of hydrocarbon shales at Etla el Zur and in the Wadi Nakheila, while the Wadi Watâ leads to Bir Himeiyid, where there is a thin coal seam.

The place called **Etla el Zur** is at the head of a short steep gully which drains into the Wadi Abu Qâda. It can be reached from the main wadi by about an hour's rough walking. The place is of interest mainly from its containing exposures of hydrocarbon shales, which are described in the chapter on stratigraphical geology (page 141). Other similar shales occur in the hills near the mouth of Wadi el Nakheila, which enters Wadi Abu Qâda about two kilometres further up its course.

Gebel Ras Um Magharab is the highest portion of the hill tract between the Wadis Abu Qâda and Watâ. The triangulation cairn on its summit occupies the site of an older and larger cairn; its position is latitude 29° 17′ 20″·6, longitude 33° 13′ 54″·4, and its altitude is 933 metres above sea-level. This cairn, being fixed in a commanding and accurately determined position, will form an important point of departure in any future surveys of the district. I reached it by a rough tramp of about two and a half hours over the hills from Wadi Abu Qâda, keeping on the west side of the **Wadi Abu el Guwari,** in the upper part of which there are palms and a well of rather salty water called **Bir Abu el Gawari.** The baggage camels ascend from a point lower down the Wadi Abu Qâda, following a very devious track for six hours to reach the summit.

Some other hills in this neighbourhood bear special names. One which I ascended about a kilometre west of Ras Um Magharab is called **Gebel Beit Salâma**; it was here that a new species of Leiocidaris was obtained.*

After completing the triangulation observations on Gebel Ras Um Magharab, I descended by a steep stony path southwards into the **Wadi Watâ,** reaching that wadi in about an hour and a quarter. Aneroid readings gave the level of the wadi floor where the track enters as 460 metres above sea, so that the total descent to this point from the beacon is about 470 metres. Following down the course of Wadi Watâ for about two kilometres, a side track was taken to the south for about half a kilometre up a little gully to **Bir Himeiyid.** Here is a pool of good water, accessible to camels, in the narrow rocky bed of the gully; a view of the pool is given on Plate XVI. There are palms a little below the well, and on either side of the palms there are thin carbonaceous shale beds, with some true coal, cropping out under the sandstone at or near the floor level; these beds will be further referred to in the geological chapter (page 149).

From Bir Himeiyid I followed the winding course of Wadi Watâ down to its junction with Wadi Abu Qâda, about nine kilometres below the well. The Wadi Watâ has here a sandy and gravelly floor

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* *Leiocidaris Balli*, Fourtau. *Catalogue des Invertébrés Fossiles de l'Egypte. Terrains Crétacés, 1re partie : Echinodermes.* Cairo, 1914, p. 5.

varying in width from twenty to a hundred metres, over which travel is easy; there is a fair sprinkling of seyal trees and retem bushes. About two kilometres below Bir Himeiyid, the steep and stony **Wadi Abu Magharab** comes in from the north-east. A kilometre further down, a dyke of dolerite, very rotten, about six metres wide, cuts vertically through a sandstone spur on the south side of the wadi with a strike about east-south-east. Three kilometres farther down, the Wadi Watâ, which up to here has coursed in a general west-south-west direction, turns off to the north-north-west; near this bend a thick dolerite intrusion cuts right up through the sandstone into the overlying Cretaceous clays and limestones, and there are black bituminous shales near the dolerite. From the bend, the wadi goes winding on in a general north-north-west direction, with hills of limestone and clays on either hand, for about three kilometres to its junction with Wadi Abu Qâda.

Wadi Abu Qâda to Gebel Hammam Faraûn.

About six kilometres below the point of influx of Wadi Watâ, and a kilometre below the place where the track from Wadi Thal enters, the Wadi Abu Qâda receives Wadi Um Lesseifa from the hills to the north-east. A kilometre further west, Wadi Heyala comes in from the south-east; from this point two black dykes can be seen cutting the white marls which form the ridge west of Wadi Heyala. Six kilometres further down its course, Wadi Abu Qâda is joined from the north-east by the Wadi Beidâ, and from this point onwards it is called **Wadi Gharandel.** The wadi now makes a big bend to the east-south-east, and expands into a small plain called **El Hennu,** limited by sandy-looking banks to the north. Four kilometres further along its course Wadi Gharandel is joined by **Wadi Silfa,** from the north, and a further kilometre brings us to the Wadi el Gurn, which comes in from the south-south-east. On the north side of the wadi here is **Gebel el Ful,** a rather high hill-mass of tumbled cream coloured rocks. Three kilometres below the point of entry of Wadi el Gurn, the track leaves the bed of Wadi Gharandel, and strikes over undulating sandy and gravelly ground south-westward for a couple of kilometres to cut off a bend. Entering the wadi again, the track continues

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down its bed, crossing the telegraph line and the Suez–Tor road about five kilometres further on, and another two kilometres brings us to **Bir Gharandel.*** This is a small pool of slightly saline water, which fills as fast as it can be emptied, in a shallow excavation of the alluvial wadi floor. There are rushes and tamarisk bushes all round the well, and some palms near by. The well is approximately sixty metres above sea-level.

At Bir Gharandel I left the wadi, and followed a winding and undulating track for about eight kilometres, at first among low hills of limestone and marls with some gypseous clays, then over gravel banks and across various drainage channels, into **Wadi Useit.** Here is a well, called **Bir Useit,*** of bad water, near a small palm clump. A headless palm trunk stands close to the well; there are other palms both above and below it. The position of the well was found by triangulation to be latitude 29° 12′ 56″, longitude 33° 0′ 49″, and its level by the same means to be 104 metres above sea.

Having important triangulation observations, which might occupy several days and nights, at the north end of the summit of **Gebel Hammam Faraûn,** I was desirous if possible of getting a light camp up the mountain. Pitching a base camp in Wadi Useit, about a kilometre further down than the well, I sent out guides to ascertain it lightly laden camels could be got up the mountain, of which the eastern slopes are much more gentle than those facing the sea. Receiving their reports that it was practicable, we ascended the following day. I went on foot, and reached the summit after about an hour's very tiring walk, at first over hills and across deep wadis, then straight up the dip-slopes of the main mountain mass. The camels had to make a long detour to the north, and took five and a half hours to reach the top, which is some 400 metres above the base camp. The low hills round the base camp consist of yellowish Miocene beds, but during the ascent these were soon passed and the rocks of the main mountain range were almost entirely chalky Eocene limestones with small nummulites, dipping gently eastward; at the summit there is a hard grey crystalline limestone which smells strongly of petroleum when struck. I spent three days and nights on the summit, the observations being delayed by haze; but I was fortunate

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* Bir Gharandel and Bir Useit have each been suggested as the "Elim" of the Israelites. *See* Stanley's *Palestine and Egypt*, London 1866, p. 69.

in obtaining, in addition to the land observations, sights across the gulf at night on to the three lighthouses of Gharib, Zafarana, and Newport rock, distant respectively 94, 31, and 87 kilometres, thus establishing a very satisfactory connexion with the Egyptian triangulation nets. The position of the beacon on the summit of Gebel Hammam Faraûn is consequently very precisely determined as latitude 29° 11′ 20″·15, longitude 32° 58′ 19″·12, altitude 495 metres above sea. The outlook from the station is very extensive. As will be seen from the view on Plate XVI, there is an almost precipitous drop at the west face of the range, where the waters of the Gulf wash the foot of the mountain. At the foot of the scarp darker greyish rocks can be seen cropping out below the white limestones which form the main mass of the range. Direct descent to the sea is impracticable, but some of my men got down to bathe in the hot springs near the sea at the north end of the range, by going northward from the station.

Gebel Hammam Faraûn to Wadi Teyiba.

After descending from Gebel Hammam Faraûn to Bir Useit (*see* page 105), I proceeded by the Suez-Tor road *viâ* Bir Thal and Wadi Shebeikha to the Wadi Teyiba. From Bir Useit to Bir Thal is a distance of about eight kilometres; the road goes over undulating sandy and gravelly plains, with a few low banks of gypseous clays and marls. **Bir Thal*** is a shallow excavation in the alluvium of Wadi Thal, near some small palms. The water is bad, being only fit for camels; but the supply is said to be perennial. Close to the well there are brownish limestones, clays, and calcareous grits of Miocene age, dipping gently westwards. Triangulation observations gave the position of the well at latitude 29° 9′ 32″, longitude 33° 4′ 26″, and its altitude as 130 metres above sea.

From Bir Thal down the **Wadi Shebeikha** to its junction with Wadi Teyiba is a distance of about five kilometres; there is a good road all the way. Near this point an igneous basic dyke cuts through the limestones bounding Wadi Teyiba, and at the contact the limestones contain hydrocarbons.

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* This lower Bir Thal must not be confused with another water source of the same name near the head of the wadi, described on p. 68.

Gebel Tanka to Suez.

In the following table I give the notes taken on the return journey to Suez. The distances were estimated by the times occupied in marching, and checked at intervals by the known positions of triangulated points. The journey can be comfortably accomplished by baggage camels in four days, moving at the rate of a little over thirty kilometres a day.

Place.	Estimated Distances in Kilometres.		Description.
	Intermediate.	Total.	
Gebel Tanka	0	0	A little north of the houses of the Sinai Petroleum Syndicate, turned off to the east by a winding track, steep in places, among white limestone hills.
Wadi Thal	12	12	Ascended the Wadi Thal for about a kilometre to
	1	13	A fine overhanging limestone bed on the south side of the wadi, giving cool shade for 100 men at all times of day. Track leaves the wadi here and goes northward to Bir Queisa.
Bir Queisa	1	14	Palms and bad water. From here, track goes over a nearly level bushy plain, with the hills of the Hammam Faraûn range on the left.
	5	19	Track strikes Suez-Tor road and follows it in a north-westerly direction.
Bir Useit	1	20	Well of bad water (*see* p. 105) in Wadi Useit.
Bir Gharandel	8	28	Well of fairly good water (*see* p. 105) in Wadi Gharandel. The track now goes up Wadi Gharandel, past Gebel el Ful, and up Wadi Silfa, a tributary of Gharandel.
Wadi Barudit ʿAmr ...	14	42	Track leaves Wadi Silfa and goes up the small Wadi Barudit ʿAmr, which enters Wadi Silfa from the east about two kilometres above the junction of Wadi Silfa with Wadi Gharandel. Then on among low banks into

Place.	Estimated Distances in Kilometres. Intermediate.	Total.	Description.
	2	44	Wadi Silfa again ; track proceeds up the Wadi Silfa, which opens out almost in a plain.
	2	46	Ground becomes undulating.
	1	47	Track descends into the drainage system of Wadi Bâqa, going down another Wadi Silfa.
Wadi Ziêta	7	54	Wadi Bâqa (called Wadi Ziêta below the point where Wadi Silfa enters). Down Wadi Ziêta to just above where that wadi passes between Gebels Khoshera and Ziêta to become Wadi Wardan to the sea. (There is said to be a very good well in the upper part of Wadi Bâqa, as good as Bir Nasib.) Gebel Khoshera is an extensive straggling hill mass of gypsum, marls, and hackly limestones, cut up by deep ravines, and the beds are much tilted about. The triangulation beacon on the summit is in lat. 29° 28′ 46″·2, long. 32° 55′ 48″·9, and is 381 metres above sea-level. I did not climb Gebel Ziêta, but it appears to be similar to Gebel Khoshera.
	7	61	Track leaves the Wadi Ziêta and turns northward, winding as a good road among low banks and hills to
Bir Hileifia	8	69	Spring of slightly saline water near a spreading seyal tree. The spring comes from under a rock and forms a pool about four metres by one and a half metres, running away by a tiny canal which soon loses itself in the sand. The Arabs say the water would be good if the place were cleaned out, but it is fouled by camel droppings at present. Besides the seyal tree, there is another tree, with a snaky stem, called *Gharqad*, which yields edible red berries.

Place.	Estimated Distances in Kilometres.		Description.
	Intermediate.	Total.	
Wadi Derba	2	71	Road crosses Wadi Derba. The hills hereabouts are of yellow limestones, probably Miocene.
Rod el Marakha	2	73	Hard calcareous grits, from which the Arabs make millstones.
Rod el Qidir	3	76	Road crosses the Rod el Qidir, and continues over undulating limestone country to
Wadi Abu Khashir ...	5	81	A broad and sandy wadi, across which the road passes very obliquely, going for about three kilometres over its bed, then on to undulating country of gypsum and marls, changing further on to limestone gravel.
Wadi Abu Niteishat .	3	84	Track crosses the Wadi Abu Niteishat, a tributary of Wadi Sudr. A little east of where the track crosses, there are overhanging rocks which give a little shade. Road continues across Wadi Sudr, which is joined by Wadi Abu Niteishat about half a kilometre west of the road, then over a sandy plain with low mounds and hills.
Wadi Kahali...	6	90	Track crosses Wadi Kahali, and continues over plain.
	4	94	Gypsum rocks close east of track, giving a little shade. Road hence to Suez practically a plain all the way, with broad and shallow drainage lines crossing it.
Wadi Lahassa	1	95	Track crosses Wadi Lahassa.
Wadi Merbâ	7	102	,, ,, Wadi Merbâ.
Wadi Qordia...	2	104	,, ,, Wadi Qordia.
Wadi Marâza	2	106	,, ,, Wadi Marâza.
Wadi Zamal Shia	2	108	Track crosses Wadi Zama Shia, and joins the Suez-Tor road, coming close to the telegraph lines.

Place.	Estimated Distance in Kilometres.		Description.
	Inter-mediate.	Total.	
Wadi Riyeina	5	113	Road crosses Wadi Riyeina.
Ayun Musa	3	116	Numerous springs, houses and gardens in a very sandy district. When a strong south wind is blowing, as was the case when I passed the place, the air is so thick with sand that observations of any kind are impossible. But I noticed that some at least of the springs are situated on the tops of sandy hillocks.
Wadi Gharqada	6	122	Road crosses Wadi Ghârqada.
El Shatt	6	128	Rest houses and telephone (no provisions) on the east bank of the Suez Canal. Suez can be reached by boat in about an hour.

CHAPTER VI.

STRATIGRAPHICAL GEOLOGY.

The various strata composing West-Central Sinai are summarized in the following table :—

System.	Division.	General Characters of Strata.	Approx. Maximum Thickness.	Some Characteristic Fossils.*
			Metres.	
PLEISTOCENE and RECENT.		Alluvial gravels and sands; wind-borne sand.		
MIOCENE.		Conglomerates, sandstones, sandy clays, and limestones. Intrusions of basalt and dolerite.	300	*Heliastraea* aff. *conoidea*; *Spatangus tuberculatus*; *Terebratula miocenica*; *Ostrea digitalina* var. *Rohlfsi*; *Pecten Josslingi*; *Pecten Fuchsi.*
EOCENE.		Limestones and clays.	400	*Nummulites* of various species; *Schizaster* aff. *vicinalis*; *Serpula spirulaea*; *Lucina metableta*; *Cardita Viquesneli*; *Collonia grandis.*
CRETACEOUS.	Campanian.	White chalky limestones with flint beds. Grey and greenish clays. White chalk.	350	*Cardita Beaumonti*, var. *depressa*; *Lucina dachelensis*; *Ostrea vesicularis* var. *proboscidea.*
	Santonian.	Yellow-brown clays, with some limestones.	100	*Echinobrissus Waltheri*; *Ostrea Nicaisei*, race *Pomeli*; *Ostrea dichotoma.*
	Turonian.	Limestones, with a basalt bed of sandstone.	100	*Cyphosoma Baylei*; *Plicatula Ferryi*; *Leoniceras segne.*

* Figures of all the fossils mentioned in this column will be found further on in the text; more complete lists of fossils are given at the end of the detailed descriptions of the different formations.

System.	Division.	General Characters of Strata.	Approx. Maximum Thickness.	Some Characteristic Fossils.*
			Metres.	
CRETACEOUS (*continued*).	Cenomanian.	Limestones, with marls and clays at the base.	200	*Holectypus Larteti; Heterodiadema libycum; Orthopsis Ruppelii; Hemiaster Heberti; Ostrea olisiponensis; Ostrea flabellata; Ostrea africana; Ostrea Mermeti; Venus Reynesi; Arca Coquandi; Eoradiolites sinaiticus; Nerinaea olisiponensis; Nerinaea bicatenata.*
CRETACEOUS to PERMIAN?	Nubian Sandstone.	Sandstones.	500	Silicified wood.
CARBONIFEROUS.	Upper Carboniferous.	Sandstones with some clay and shale bands.	150	*Lepidodendron.*
		Limestones with some earthy layers. (Iron and manganese ores at base in places.)	40	*Zaphrentis, Syringopora ramulosa; Favosites Michelini;* Crinoid stems; *Fenestella; Orthis Michelini; Productus longispinus; Spirifer striatus; Spirifer* cf. *moosakhailensis; Chonetes hardrensis; Rhynchonella pleurodon; Athyris Roysii; Athyris lamellosa; Athyris planosulcata; Terebratula (Dielasma) hastata; Hinnites sp; Bellerophon tenuifascia.*
	Lower Carboniferous.	Sandstones with some shales.	130	Medusae, worm-tracks and other markings.
PRE-CARBONIFEROUS.		Granites, diorites, gneisses and schists, with dykes of felsite and porphyry.		

* Figures of all the fossils mentioned in this column will be found further on in the text; more complete lists of fossils are given at the end of the detailed descriptions of the different formations.

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PLEISTOCENE AND RECENT.

The Pleistocene and Recent deposits comprise two classes, the one resulting from the action of running water, the other from that of the wind :—

1. *Alluvial deposits*, boulders, gravel, and sand.
2. *Aelian deposits*, wind-borne sand.

Alluvial Deposits.

The greater portion of all the wadi floors is composed of alluvial detritus brought down by the streams which occasionally descend the valleys after rainfall in the hills. The characters of these deposits vary with the nature of the rocks composing the hills, and with the degree of slope of the drainage channel. In the steep ravines of the igneous regions, they consist of huge blocks and boulders of granite and similar rocks, tumbled in a confused mass, with gravel and sand filling the interspaces. As one descends into the lower reaches of the greater valleys, especially those draining sedimentary areas, the boulder deposits gradually give place, as the slope becomes flatter, to gravels and sands. The continuity of the alluvium is often interrupted where hard rocks crop out in the wadi floor ; but these interruptions become less frequent as the mouths of the channels are approached, and the terminal portions of all the great wadis have thick deposits of sand and gravel covering their floors.

In some of the valleys, particularly the upper parts of Wadis El Lahian and El Sahu, as well as in the little tributary of Wadi Thal called Wadi Lughb, there are considerable accumulations of gravel, through which the present day drainage has cut its way, leaving high banks on each side, often more than ten metres high. Though from their position along the existing drainage lines these accumulations cannot be older than the Pleistocene, they evidently date back from a time when the rainfall was greater than at present, and the streams were of sufficient volume to distribute the detritus over the whole width of the valleys.

On the broad coast plain of El Markhâ the streams debouching from the hills spread out and deposit most of their detritus before reaching the sea. This plain is consequently covered with gravel and sand. In the north-east corner of the plain there is a tract covered

with boulders, due to the bringing down of great blocks of rock from the steep ravines which drain Gebel Samrâ; but the bulk of the plain is covered with gravel of moderate coarseness, composed of a mixture of igneous pebbles, fragments of sandstone and limestone, more or less angular flints derived from the Cretaceous beds, and flint pebbles from the Miocene conglomerates. The gravel is mixed with a good deal of sand, but sand is less conspicuous than the gravel itself, as it is being continually distributed by the wind, accumulating in the hollows between the stones, which are swept bare. The thickness of the alluvial deposits on the plain is unknown; but the more impetuous of the streams, such as that which occasionally descends Wadi Dafari, have cut channels to depths of five or six metres through it, and it doubtless far exceeds this in average thickness.

Aelian Deposits.

Along the foot of Gebel el Tih to the east of longitude 33° 15′, there extends a nearly plain tract in which blown sand is the most conspicuous feature. For about five or six kilometres from the face of the scarp, the sand is mainly seen in the broad drainage lines of Wadi el Hommur and its feeders, and swathing the sides of the low hills which rise from the plain; but further south the sand is more heavily accumulated, forming the Debbet el Qeri, over which one can march for miles without setting foot on anything but sand. At the southern limit of the sandy tract there is a rather abrupt drop into the deeply cut heads of the various feeders of Wadi Baba, and as the level of the sand is highest (*see* the section in Fig. 7 on page 88) just before the drop commences, it is obvious that the sand accumulation is gradually progressing southwards. In character, the sand of this region is just like the dune sand of Egypt; it is composed of well rounded grains of quartz, about a millimetre in average diameter, covered by a thin yellow film of iron oxide, with a small admixture of calcareous grains. But there is no further resemblance to the great dunes of the western desert of Egypt; dunes in fact are here practically absent, unless we regard the whole mass as one great broad dune. The tract of Debbet el Qeri is really a sandy plain in which the sand is partially bound up into a sort of soil by a fair sprinkling of vegetation. We had to remove quite a large number of bushes in order to clear our base line for measurement. The principal bushes are those called

by the Arabs *ʿadam*, *retem*, and *qirsha*. Most of the plain is quite passable for camels, the sand as a rule yielding only a centimetre or two under their feet; but the drifts on the sides of the hills, and the south slopes where the plain drops into the Wadi heads, are very soft.

It is remarkable that where the drifted sand is in the near vicinity of Carboniferous sandstone, as for instance to the east of Gebel Musabaʿ Salâma, the usual golden yellow colour gives place to a decidedly reddish tint. As the Carboniferous sandstones are typically redder than the ordinary (Cretaceous) Nubian sandstone of Gebel el Tih, we infer that the sands have not travelled any great distance from their place of origin. The sand of the Debbet el Qeri is derived from the Nubian sandstone of Gebel el Tih, the material produced by the weathering back of the scarp being blown to the south. The prevailing wind over the scarp of El Tih, at any rate in the winter, is from the north; it may be also worth remark that as the scarp faces to the south, it is heated by the sun's rays in the day, and the diurnal variation of temperature, which is probably the main disintegrating agent, is thus able to exercise its maximum activity in the breaking up of the exposed rocks.

Besides the great accumulation of blown sand of the Debbet el Qeri, there are some minor patches of blown sand, often very sharply defined, on scarps or hill flanks. An instance of this is the fan-shaped deposit on the hill side west of Bir Nukhul. Such isolated accumulations are always in wind shadows, but it is not quite clear why the deposits occupy particular places of this kind to the neglect of others apparently equally eligible. The whole question of the natural selection of site for sand dunes is obscure; most likely there is some influencing condition of which we are as yet ignorant.

The coastal plain tract which extends south-eastward from Suez past Ayun Musa (Moses' Springs) is largely covered by sand which is being continually redistributed by the winds. Where there is a strong south wind, the air in the neighbourhood of Moses' Springs is frequently so thickly sand-laden that travel is extremely uncomfortable, and it is impossible to see more than a few yards ahead. As Mr. Barron found that there is evidence for a recent rise of the coast in this neighbourhood,* the sand here may be in part derived from an ancient sea bottom.

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* Round the springs there is a recent beach lying fifteen to twenty metres above the sea, and east of the wells is a bank of oysters which have not yet lost their colour. *See* BARRON. "Peninsula of Sinai (Western Portion)," Cairo 1907, p. 101.

MIOCENE.

Miocene deposits occur as isolated patches, often of considerable extent, at various places on the western side of the great fault which cuts across the junction of Wadis Baba and Shellal and strikes a little west of northward along the western flank of the Gebel Abu 'Edeimat. One large tract of Miocene rocks extends on both sides of the Wadi Baba a little way up from its mouth, and ends on the plain of El Markhâ near the foot of Gebel Samrâ. Another stretches from near

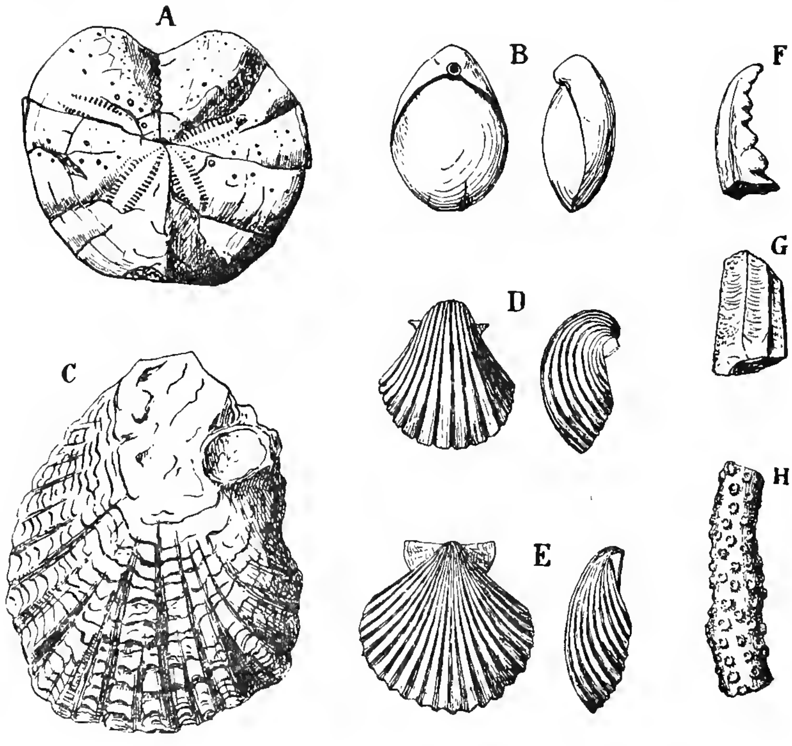

FIG. 8.—Miocene fossils. A, *Spatangus tuberculatus* Wright; B, *Terebratula miocenica* Basterot; C. *Ostrea digitalina* Eichwald var. *Rohlfsi* Fuchs; D, *Pecten Jossling* Smith; E. *Pecten Fuchsi* Fontannes; F and G, appendages of crabs; H. *Heliastraea* aff. *conoidea* Reuss. A–C are from near the mouth of Wadi Baba; D–H from near Gebel Tanka. The figures are slightly reduced from the natural size.

Bir el Markhâ north-westwards to Wadi Nukhul. A third, of less extent, forms a steeply scarped hill-mass west of Gebel Nukhul. A fourth, cut into two by the Wadi Teyiba, caps Gebel Sarbut el Gamal and the western part of Gebel Musaba' Salâma. And a number

of smaller patches occur further north-west, close alongside the great fault, forming the flanking hills of Gebel el ʿIseila and Abu ʿEdeimat.

Besides the above-mentioned areas, the shape and distribution of which are shown on the map on Plate I, deposits of Miocene age are found at the mouth of Wadi Teyiba, on the top of the low scarp of Gebel Tanka and on the hills to the north-east of this place ; near the middle of Wadi Thal ; Near Bir Useit ; at Gebel Gushia ; at Gebel Ful, on the north side of Wadi Gharandel ; at Gebels Khoshera and Ziêta, on either side of the Wadi Wardan ; and doubtless at other points in the coastal tract between Abu Zenima and Suez.

The Miocene beds comprise a considerable variety of rocks, ranging from basal conglomerates and gritty limestones, with corals and pectens indicative of littoral conditions, through sandy and calcareous clays, to clays and limestones which must have been deposited in a sea of some depth. In Figure 8 are shown some of the commoner Miocene fossils of this part of Sinai. The Miocene beds have a prevalent yellow colour, but as many of the underlying Eocene beds, and some Cretaceous ones, have the same characteristic, the limits are not always easy to trace in the field without examination of the fossil contents.

In the Miocene area near the mouth of Wadi Baba, thick beds of conglomerates, made up of flint pebbles and boulders set in a calcareous cement, are very prominent in the hills abutting on the coast close south of El Mereighat, and extend inland along the cable route, where they are reared up on edge by faulting, and form the narrow ridges and spikes of some of the highest hills of this tract. The conglomerates are overlain by beds of gritty limestone, and as one proceeds southwards, beds of greenish sandy shales and yellowish limestones with Pectens become the dominant rocks.

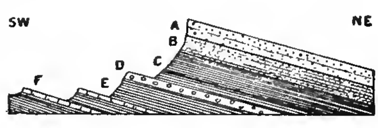

FIG. 9.—Section across the Miocene scarp between Bir el Markhâ and the Wadi Nukhul. A, Grits with *Pecten*, etc.; B, Yellowish sandy clays; C, Red and white clays; D, Boulder bed of nummulitic limestone; E, Red, white, and yellow clays with small nummulites; F, Yellow-brown gypseous clays with some marl beds.

A section across the Miocene beds which extend north-westwards from near Bir el Markhâ to the Wadi Nukhul is shown in Figure 9. The uppermost Miocene beds are here formed by a great thickness, some forty metres, of grits, containing Pectens; the western edges of these beds form a nearly vertical scarp, practically unclimbable

at most points. Below the grits comes a considerable thickness of yellowish sandy clays, probably also of Miocene age. Then come red and white clays, in the lower parts of which small nummulites were found. It is possible that these small nummulites are derived fossils, but I am inclined to think that the clays are here the uppermost Eocene beds. All the beds appear to be conformable. When traced eastwards, the Miocene grits are cut off by a fault which brings the Upper Cretaceous beds to the surface.

The Miocene-capped hill mass close west of Gebel Nukhul likewise presents a very steep escarpment to the west, the beds dipping inwards towards the fault which has brought up the Carboniferous strata to the level of the Miocene. The beds here consist of conglomerates with overlying calcareous grits and limestones. Here, too, they appear to be conformable to the underlying Eocene, but the disturbance caused by the fault is so great that a small unconformity might be easily overlooked.

At Gebel Sarbut el Gamal, conglomerates are again a conspicuous feature at the base of the Miocene, being developed in great thickness. They are overlain by gritty limestones containing corals, pectens, and flattish echinoids; but with the exception of the corals the fossils are commonly found only in fragments, often highly crushed.

At the mouth of Wadi Teyiba the Miocene beds, consisting of conglomerates, sandstones, and marly clays, contain in their lower part a thick sheet of basalt which apparently lies concordantly with the beds above and below it. The beds here dip towards the sea, and overlie Eocene rocks; I found nummulites in the red laminated marly limestone a few metres below the basalt, as mentioned by Blanckenhorn.*

On the top of the scarp close to the sea at Gebel Tanka the Miocene beds consist of yellow marls and clays with thin sandy beds containing Pectens, and a thin sandstone covering. Below these (*see* Fig. 11 on page 127) come purple clays which are probably Eocene, overlying thickly-bedded yellowish Eocene limestones with marly bands, containing *Schizaster* aff. *vicinalis* Ag. The Miocene here appears to overlie the Eocene conformably. In the tract of white hills which extends eastward and north-eastward from Gebel Tanka to the Wadi

* "Das Miocan," *Zeitsch. der Deutsch. Geol. Gesellsch.*, 1901, Heft 1, Band 53, s. 77.

Teyiba, Miocene beds also occur, but they are here cut up by the numerous drainages, which have exposed the underlying Eocene and left the Miocene capping the hills; the limits of the Miocene hereabouts are extremely difficult to trace on account of the absence of any marked lithological differences between them and the underlying Eocene and Cretaceous beds. From a camp at the bend in Wadi Teyiba, just below where the Wadi Shebeikha enters it from the north, I ascended one of the higher hills* of this tract, climbing over chalk and chalk marls, without any suspicion that the rocks passed over were other than the higher beds of the Campanian, until some thirty metres below the summit, where I found a bed containing *Pecten Fuchsi*, proving the rocks at this level to be Miocene. At lower levels on the western flanks of the hill I found abundance of Eocene fossils. The beds here dip at 6° to the north-east, and there appears to be absolute conformity between the Miocene and Eocene. A north and south fault along or near the Wadi Teyiba appears to have thrown up the Tertiary beds against the Cretaceous.

In the middle of the Wadi Thal, according to Barron,† the Miocene is represented by marly sandstone and limestone, with veins of gypsum, dipping 28° north-west, containing, amongst other fossils, *Pecten cristato costatus* and *Ostrea Virleti*. Close to Bir Thal I found brownish limestones with pectens, clays, and gritty limestones, dipping gently westwards.

Near Bir Useit, close to the eastern flanks of Gebel Hammam Faraûn, yellowish Miocene strata, consisting of marly beds with gypsum overlying sandy calcareous beds with pectens and oysters, are found in a synclinal fold, from under which the white Eocene limestone crops out westwards (*see* view on Plate XVIII).

At Gebel Gushia, according to Barron, the Miocene consists of a hard calcareous sandstone, with layers of flint pebbles, overlying gypseous marls.

At Gebel el Ful, on the north side of Wadi Gharandel, the Miocene consists of cream coloured rocks, apparently much tumbled about, in which Barron‡ made out the succession from above downwards

* This hill, marked by a triangulation cairn, is about four kilometres north-north-east of Gebel Tanka and about a kilometre west of the bend in Wadi Teyiba. The cairn on the summit is in lat. 29° 7′ 17″, long. 33° 5′ 5″, and is 242 metres above sea-level.

† "Western Sinai," p. 118.

‡ *Op. cit.*, p. 119. Barron calls this hill Gebel Khoshera.

to be: (1) beach limestone with corals and pectens; (2) whitish marly limestone with *Ostrea Virleti* and *O. digitalina*; (3) greyish marls with oysters and gasteropods.

At Gebel Khoshera, on the south side of the Wadi Wardan, the Miocene is represented by gypsum, marls, and hackly limestone. The beds are of considerable thickness, the whole hill mass, which rises to 381 metres above sea, being apparently composed of them; but they are so tumbled about that it is difficult to make out the succession. Gebel Ziêta, on the north side of the Wadi Wardan, appears to be of similar composition. Amongst the fossils collected from Gebel Ziêta, M. Fourtau has identified specimens of the rare genus *Jouannetia*, a boring mollusc which has also been recorded from the Miocene of Corsica.

To sum up the Miocene of this part of Sinai, the more easterly portions of the deposits are characterized by great accumulations of conglomerates and grits, indicating that the old shore line ran approximately along the line of the great fault already referred to, while further to the west there is increasing predominance of limestones, marls, clays, and gypsum, indicating deeper water conditions for certain beds. The inferences from lithological characters are borne out by the fossil contents of the rocks, the abundance of corals, oysters, and pectens, and the occurrence of sea urchins of the genera *Spatangus*, *Lovenia*, and *Echinocardium*, indicating a littoral facies for the more eastern of the deposits, while for the rocks near Gebel Tanka, further off the ancient shore line, *Lepidopleurus* and *Brissopsis* point to a deeper water origin. Regarding the maximum thickness of the deposits, only a rough estimate can be made, as the whole series is not exposed at any one place; it probably exceeds 300 metres. As to the extent of the Miocene sea, it was probably continuous right across what is now the Gulf of Suez, the present isolated patches being the remains of a single large one, of which the greater portion has been removed by denuding agencies, assisted by complicated earth movements. The great development of gypsum in the Miocene at Gebels Khoshera and Ziêta is similar to that observable on the other side of the Gulf further south, in the neighbourhood of Jemsa, and the correspondence suggests an extensive Miocene sea.

Miocene beds overlying Eocene limestone east of Gebel Hammam Faraûn.

View in the hills near the mouth of Wadi Teyiba, showing characteristic weathering of marls and clays.

List of Miocene Fossils.

Collected by the Author and Determined by Mr. R. Fourtau.

Actinozoa :—

Heliastræa aff. *conoidea* Reuss, Gebel Tanka.

Various other corals, not yet determined.

Echinoidea :—

Cidaris cf. *avenionensis* Desmoulins (spines), west of Gebel Nukhul.

Lepidopleurus sp. nov., Gebel Tanka.

Clypeaster sp., Wadi Baba.

Brissopsis Fraasi Fuchs, Gebel Tanka.

Schizaster sp. ind., west of Gebel Nukhul.

Echinocardium depressum Agassiz, north-west of Bir Markhâ.

Maretia tuberosa Fraas, north-west of Bir Markhâ.

Lovenia sp. nov., north-west of Bir Markhâ.

Hemispatangus Fuchsi Oppenheim, north-west of Bir Markhâ.

Spatangus tuberculatus Wright, west of Gebel Nukhul and Wadi Baba.

Molluscoidea :—

Terebratula miocenica Basterot, Wadi Baba.

Mollusca :—

Pecten Josslingi Smith, Gebel Tanka.

Pecten Fuchsi Fontannes, Gebel Tanka, north-west of Bir el Markhâ, and south of Gebel Abu 'Edeimat.

Pecten cristatocostatus Sacco, Gebel Tanka.

Chlamys Gentoni Fontannes, Gebel Tanka.

Chlamys gloria-maris Dubois, Gebel Tanka.

Ostrea digitalina Euchwald, var. *Rohlfsi* Fuchs, Wadi Baba.

Ostrea vestita Fuchs, South of Wadi Baba.

Ostrea aff. *caudata* Munster, north-west of Bir el Markhâ.

Ostrea aff. *excavata* Deshayes, Gebel Tanka.

Ostrea lamellosa Brocchi, north-west of Bir el Markhâ.

Ostrea Virleti Deshayes, Wadi Baba.

Crustacea :—

Appendages of crabs, Gebel Tanka.

VOLCANIC INTRUSIONS OF THE MIOCENE PERIOD.

The sedimentary strata of West Sinai have in numerous localities been intruded by basic volcanic rocks, forming dykes and sheets of dolerite and basalt. These volcanic deposits, which are found penetrating the strata of various ages from Carboniferous to Miocene, were probably all derived from the same magma, and all injected during the Miocene period.

The most considerable of the volcanic deposits is the thick sheet of basalt which forms the cap of Gebel Farsh el Azraq and the neighbouring hills. This sheet occurs in the Upper Carboniferous sandstone; its thickness in some places exceeds seventy metres, and it extends over several square kilometres of country. The sheet was doubtless once continuous, intervening rock between the now isolated portions having been removed by the erosion of drainage channels. The basalt frequently shows well marked columnar structure (*see* the views on Plate XIII). The deposit, though it appears at most points to be a single bed, is found at several places to consist of several distinct sheets, penetrating the sandstone along its planes of stratification at different levels. This clear evidence of the intrusive character of the basalt is well seen in the hills to the west of the little Wadi Rekeis, which enters Wadi Sahu near the tomb of Sheikh Hashash.

Smaller massas of basalt occur capping Gebels Sarabit el Khâdim and Abu Treifia, while sheets of considerable thickness and extent are found in the highly faulted country to the south of Wadi Shellal, and in the hills west of Gebel Hazbar. At all these places the basalt occurs in sheets running along the planes of stratification of the Upper Carboniferous sandstone, and the latter rock has generally been hardened to quartzite for a thickness of a metre or so at the contact.

Another thick sheet of basalt occurs in the scarp of Gebel el Tih, where it can be traced round for a distance of over eight kilometres. The thickness of the basalt here averages about twenty metres. The sheet is intercalated in the Cretaceous beds between the top of the Nubian sandstone and the base of the Cenomanian clays, and might from a casual inspection be thought to be a contemporaneous deposit between these two formations. But in the hill which flanks Gebel

el Sâlia on the west the sheet is seen to turn vertically upwards, cutting right through the Cenomanian beds (*see* Fig. 18 on page 139) and its later intrusive origin is thus clearly indicated.

A smaller dolerite sheet, about ten metres thick, underlies the Turonian limestone bed which forms the top of the Tih plateau near Gebel Ras Watâ; the volcanic rock, which is here weathered into a very rotten condition, has altered the limestones at the surface of contact.

A dolerite deposit, of which the intrusive nature is still more clearly evident, is the great dyke which can be traced for some seventeen kilometres in a north-westerly direction from the Wadi el Sih across the low sandstone country and which cuts the scarp of Gebel el Tih in the corner north-east of Gebel Shushet Abu el Nimran. This dyke has a width of about fifty metres in the little Wadi el Kiheila. It has hardened the Carboniferous and Nubian sandstones to quartzite on either side of it along its entire course. Where it cuts the Cenomanian limestones and marls of Gebel el Tih, it passes gradually into a thin sheet only some half a metre in thickness, and here it has altered the limestone into a black crystalline form which strongly resembles the basalt itself in appearance.

A smaller dyke, probably an offshoot of the one just described, cuts along the hills to the south of Wadi el Kiheila, and dies out in a thin tongue of semi-glassy rock.

On the eastern flank of the hills forming the north end of the range of Gebel Matulla, there is a doleritic intrusion, perhaps an inclined dyke, cutting through the Senonian clays and marls. This intrusion, which has a width of about thirty metres, was traced for about two kilometres; it was observed to have hardened the clays and marls along its sides. Some of the limestones in the neighbouring Rod el Ghada, which were found to smell strongly of petroleum when struck, may possibly owe their hydrocarbon contents to the action of this doleritic intrusion.

A small dolerite dyke about six metres wide cuts across Wadi Nukhul near its mouth, and is possibly continuous with a similar one which cuts across Wadi Teyiba. At both these places the Senonian limestones, where penetrated by the dyke, are darkened, and smell of hydrocarbons when struck.

Near the mouth of Wadi Teyiba there are two sheets of basalt in the Miocene rocks, one close to the mouth of the wadi, and another farther inland. Probably, as Barron remarks, these two sheets are portions of one and the same deposit, separated by the complicated faulting which has taken place hereabouts. In the view on Plate XIX, which was taken from a hill looking southward across Wadi Teyiba, the basalt is seen near both the right and left hand edges of the picture. The sheet near the mouth of the wadi is about twelve metres thick, and has the appearance of an interbedded lava.

Several other doleritic intrusions exist in the district besides those above described, especially in Gebel Hammam Faraûn and the hills to the east of it. At Hammam Faraûn, according to Mr. Murray,* a lava sheet about forty-five metres thick occurs in the Cretaceous limestones and shales, and is exposed along the sea face of the mountain, and the range is also cut by a large dyke.

As regards the age of the basalts and dolerites of West-Central Sinai, Barron concluded from his observations that the rocks belonged to two groups, one Carboniferous and the other Miocene in age. The remarkable way in which the main basalt sheet in the Carboniferous sandstone follows mostly a definite horizon, lent, in the absence of further evidence, a good deal of support to this view. But the later observations recorded above conclusively establish the intrusive character of the basalt in the Carboniferous rocks, and the tendency to extend along a particular geological horizon is paralleled in the persisting of the sheet between the Nubian sandstone and the Cenomanian marls of Gebel el Tih, where the intrusion is proved to be later than the Cenomanian by the passage of the horizontal sheet into a vertical dyke. When we compare the basalts and dolerites among themselves, the characters of those which have intruded the Carboniferous rocks appear to differ in no essential respect from those injected into the Cretaceous beds of those which occur interbedded in the Miocene; there are, of course, differences of grain corresponding to various rates of cooling, depending on the variations in thickness of the deposits and on differences in the pressure of the overlying strata. But so far as can be gathered from microscopic examination (a detailed petrographic and chemical comparison, though much to be desired, has

* "Cairo Scientific Journal," 1913, p. 22.

View from a hill near the mouth of Wadi Teyiba.
(Faulted area of Cretaceous, Eocene, and Miocene rocks, with basaltic sheets.)

not been undertaken up to the present) the differences between the rocks of these various intrusions are no greater than can be accounted for by differences in the conditions of solidification and of subsequent weathering, and consequently it appears justifiable to refer all the intrusions to one and the same magma, and to the same geological period. That period must be the Miocene, because some of the deposits are interbedded in Miocene rocks; and the intrusions cannot be younger than the Miocene, because the faulting which took place at the close of the Miocene has involved the basalts equally with the rocks into which they have been injected. The intrusions most likely took place at the commencement of the great earth movements; one can easily picture the first fractures allowing the escape of the molten magma up them, and the first foldings giving rise to easier passage for the magma along those definite planes in the stratified rocks where the volcanic rocks are conspicuously found.

As a corollary to the above conclusion, it is an interesting speculation as to whether all the intrusions of basaltic rocks found over a wide extent of longitude in the north of Egypt, such as for instance those of Abu Zabel near Cairo, the Oasis of Baharia, and the Wadi Araba, may date from the Miocene period and have been derived from a single magma. A late Tertiary age has already been assigned to most of them, and so far as petrographic studies of the different occurrences have progressed, they appear to support the idea of a common origin. It is hoped at a later date to accomplish a detailed petrographical and chemical examination of the various rocks in order to test this point.

EOCENE.

Strata of Eocene age are exposed among the low hills to the south of the junction of the Wadis Baba and Shellal; on both sides of the Miocene area which extends north-westward from near Bir el Markhâ to the Wadi Nukhul; round the western foot of the Miocene scarp west of Gebel Nukhul; in the ridge on the west side of the little Wadi Memlaha; in the scarp of Gebel Tanka abutting on the sea and in the hills to the north-east of this place; near the mouth of Wadi Teyiba; in the great hill range of Gebel Hammam Faraûn; at Gebel el Heyala and Gebel Krer; at Gebel el Abiad; and in the north-western portion of Gebel el Tih.

To the south of the junction of Wadi Shellal with Wadi Baba, the Eocene beds consist of yellowish clays and marls, containing *Nummulites gizehensis*, *Serpula spirulœa* and *Pectunculus pyramidarum*; the beds here are steeply tilted into a series of north and south ridges by faulting.

On the western side of the Miocene scarp which extends north-westward from near Bir el Markhâ, there is a tract of parallel ridges striking north-west, consisting (*see* the section, Fig. 9, on page 117) of:—

1. (Top). Red and white clays with small nummulites.
2. Boulder bed of nummulitic limestone.
3. Red, white, and yellow clays with small nummulites.
4. Yellow brown gypseous clays with some marl beds and yellowish limestones containing *Nummulites gizehensis*, *Serpula spirulœa*, *Collonia grandis*, *Turritella Lessepsi*, and various sharks' teeth.

The beds all dip at about 15° to the north-east. They appear to overlie conformably the Cretaceous beds of the coastal hill ranges, and to be in turn conformably overlain by the Miocene sandy clays and grits. The total thickness of the Eocene here is estimated at about 300 metres, of which by far the greater portion consists of the lowest of the four groups above mentioned. Like the underlying Cretaceous limestones, the Eocene limestones contain flint beds, and the exact limit between the two is not easily traced except by searching for fossils; but the Eocene limestones hereabouts are typically of a yellower aspect than the Cretaceous rocks. There seems to be a gradual increase in the proportion of limestones to clays and marls from the south to the north end of the Eocene tract.

On the eastern side of the Miocene grits which overlie the rocks just mentioned, a fault brings the Cretaceous up against the Miocene along the greater portion of its boundary; but about two kilometres to the north-west of Bir el Markhâ the Eocene crops out again as a series of highly tilted strata, well exposed in a small southward-draining wadi close to the fault. From Figure 10, which gives a sketch section at this point, it will be seen that the Eocene beds retain the same general characters as on the other side, but they are here highly inclined and squeezed out by the faulting.

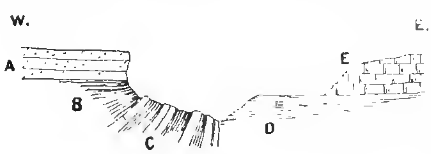

Fig. 10.—Section across the fault about two kilometres north-west of Bir el Markhâ. A, Miocene grits; B, Red and white clays; C, yellow-brown clays and marls (Eocene); D, Santonian clays; E, Campanian chalk.

Round the western foot of the high Miocene scarp which forms the western flank of Gebel Nukhul, there extends a tract of lower hills and ridges of yellow aspect, composed of marls and clays in which sharks' teeth and *Serpula spirulœa* were found.

To the east of Wadi Nukhul, in latitude 29° 4′, there is a high ridge of yellowish marls and clays, on the western slopes of which are gravels and boulders of crystalline nummulitic limestone. The beds dip at about 30° to the west, and on the eastern side of the ridge, in the little Wadi Memlaha, there are traces of the underlying shales and clays having been worked on a small scale for nitre. The structure here was not very clear, but the impression I got was that the ridge was Eocene, the Campanian chalk being thrown up by a fault at its western foot, while the nitrate-bearing shales and clays, which crop out on the eastern side owing to the strong westerly dip, are passage beds between the Cretaceous and Eocene.

In the scarp which stretches along the coast at the oil wells of Gebel Tanka (*see* Fig. 11) there are three well marked series of beds exposed. Counting from above downwards, these are: (1) a series of yellow marls and clays, with thin sandy beds and a thin sandstone covering; this series is of Miocene age, as shown by the Pectens and other fossils contained in it; (2) a considerable thickness of purple clays, in which I found no fossils, but which I believe to be Eocene, corresponding with the red sandy clays containing nummulites found at the mouth of Wadi Teyiba and to the north-west of Bir el Markhâ; and (3) thick beds of yellowish limestones with marly bands, from which a number of echinoids, recognized by Mr. Fourtau as closely related to *Schizaster vicinalis*, were obtained, and for which an Eocene age is thus indicated. The beds dip at some 10° inland.

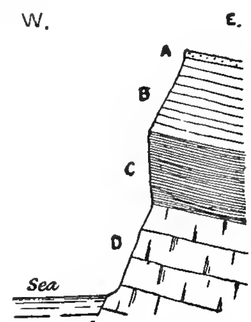

FIG. 11.—Section of scarp at Gebel Tanka. A, thin sandstone bed; B, yellow marls and clays with thin sandy beds (Miocene); C, purple clays; D, yellowish limestone (Eocene).

In the hilly tract between Gebel Tanka and the Wadi Teyiba, Eocene beds have a considerable extent, though as this area has not been mapped in detail their precise distribution is unknown. From the view shown on Plate XIX, which was taken looking southward from the summit of a hill four kilometres east-north-east of Gebel Tanka,

it will be seen that the structure is complicated by folding and faulting, and it is difficult without careful detailed mapping to get a clear idea of the limits of the different formations. There is in this district so strong a lithological similarity between the Eocene and Miocene on the one hand, and between the Eocene and Upper Cretaceous beds on the other (all three formations consisting mainly of chalky rocks), that fossil evidence is almost the only sure guide in separating them. The evidence of the presence of the Eocene was gathered in descending from the above-mentioned hill towards Gebel Tanka, when a large number of typical Eocene fossils were found, including *Serpula spirulæa*, *Lucina metableta*, *Cardita Viquesneli*, and *Collonia grandis*. The chalk and chalk marls from which these fossils were obtained are so similar in character to the Campanian beds further east, that but for the finding of the Eocene fossils I should certainly have regarded the beds as Cretaceous, as Barron did. In the hill where the fossils were found, the Eocene beds dip at 6° to the north-east, and are conformably overlain by the Miocene. They are probably cut off by a fault running north and south along or near the Wadi Teyiba, bringing them alongside the Campanian; but of this I could not make absolutely certain. As the Campanian beds are themselves almost devoid of fossils and are undistinguishable lithologically from the chalk and marls of the Eocene, it may easily be the case that a part of the chalk extending eastwards to near Sarbut el Gamal is really Eocene, though in the absence of any fossils or unconformity I have followed Barron in mapping it as Cretaceous.

At the mouth of the Wadi Teyiba, nummulites belonging to the group *contorta-striata* were obtained from red marls just below a thick sheet of basalt; but the extent of the Eocene must here also remain unknown until further detailed mapping is undertaken.

In the high hill range of Gebel Hammam Faraûn are Eocene deposits consisting of a great thickness of white chalky nummulitic limestone. The beds here dip at some 10° or so away from the sea, and have a thickness of at least 300 metres. The top bed at the north end of the range consists of a hard grey crystalline limestone, smelling strongly of petroleum when struck; the rocks below it gave, however, no smell when subjected to the same test.

At Bir el Queisa, to the east of the Hammam Faraûn range, I found limestones containing *Cardita Viquesneli* and *Turritella* cf. *heluanensis*.

At Gebel el Heyala the Eocene beds consist of nummulitic limestone. The section in Figure 12 was sketched just below the head of Wadi el Heyala. It will be seen that the nummulitic limestone which caps the range is underlain by grey clays, which doubtless correspond to the Esna shales of the Nile Valley and form the uppermost Cretaceous strata. The structure of Gebel Krer, a high ridge to the west of Gebel el Heyala, appears to be similar, though Barron does not indicate any intervening clays between the nummulitic limestone and the underlying chalk.*

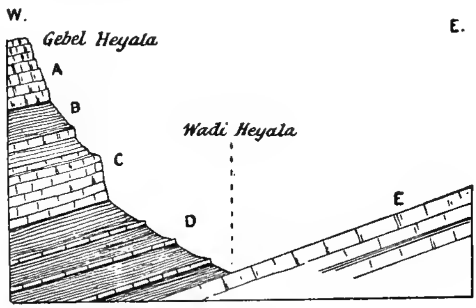

FIG. 12.—Section across Wadi el Heyala just below its head. A, Nummulitic limestone; B, grey clays (Esna shales); C, snow-white chalk marls (Campanian); D, grey laminated clays with brown earthy and gritty limestone beds and some marly bands (Santonian?); E, limestones with some marls and clays of a prevalent brown colour (Turonian and Cenomanian?).

At Gebel el Abiad, Barron found nummulitic and operculina limestones, to which he assigns an Upper Eocene age, unconformably overlying Campanian limestones with a dip of about 5° to the south-west.

In the northern part of the western scarp of Gebel el Tih, nummulitic limestone extends, according to Barron, southwards to a little beyond Gebel Sin Bisher, from which point it descends into the plain.

In Figure 13 are represented the Eocene fossils most commonly met with in and near the area surveyed in detail. The most distinctive and characteristic forms are the nummulites and the flat spiral shell of the worm *Serpula spirulœa.*

As contrasted with the corresponding strata of the Egyptian side of the Gulf of Suez and of the Nile Valley of Egypt, the Eocene of this part of Sinai is comparatively thin, probably nowhere exceeding 400 metres in thickness, and only approaching that figure in the north-western portion of the district, near Gebel Hammam Faraûn. From this comparative thinness and the marked littoral character of many of the fossils, one is inclined to infer that, like the Miocene, the Eocene

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* "Western Sinai," Section IV. In Barron's section, the eastern one of the two hills called Gebel Krer is my Gebel el Heyala.

deposits did not extend far to the east of their present limits in this locality. But in this view one must not be too positive; the boulder beds of nummulitic limestone visible to the east and south of Wadi Nukhul indicate the former presence of limestone beds removed by

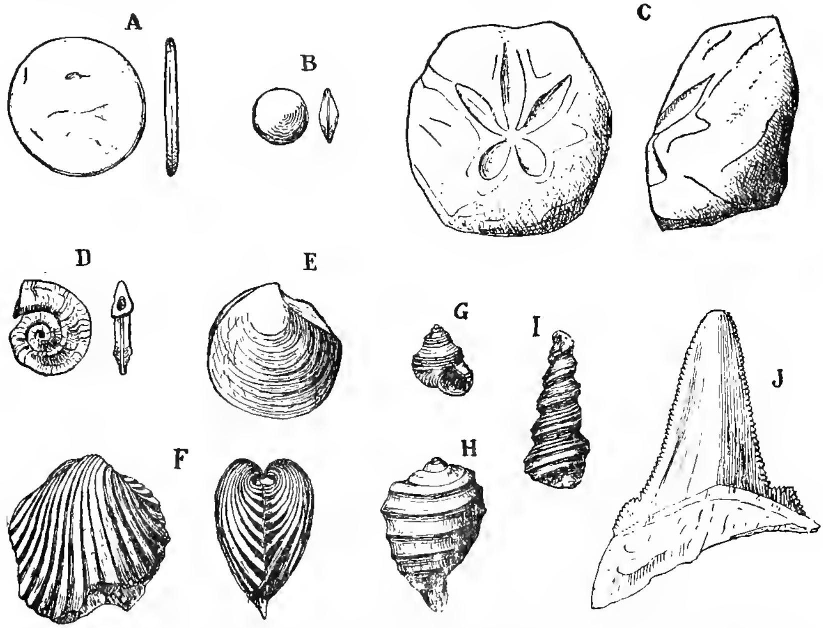

FIG. 13.—Eocene Fossils. A, *Nummulites gizehensis* Ehrenberg, var. *Pachoi* de la Harpe; B, *Nummulites* of the *contorta-striata* group; C, *Schizaster* aff. *vicinalis* Agassiz; D, *Serpula* (*Rotularia*) *spirulaea* Defrance. E. *Lucina metableta* Cossmann; F, *Cardita Viquesneli* d'Archiac et Haime; G, *Collonia grandis* Oppenheim; H, *Cassis aegyptiaca* Opphm.; I, *Turritella helwanensis* Mayer-Eymar; J, *Carcharodon auriculatus* Blainv.

A, from south of Wadi Baba; B, from the mouth of Wadi Teyiba; C, from the foot of Gebel Tanka; D, G and J, from south of Wadi Nukhul; E, H, and I, from the hills east of Gebel Tanka.

All the figures are slightly less than the natural size.

denudation before the Miocene period set in. That there is usually apparent conformity of the Eocene with the Cretaceous below and the Miocene above is in large part probably due to the rise and fall of the crust being of a regional type until after Miocene times, when the complicated folding and faulting occurred which has tilted and fractured the beds into their present positions.

Like the underlying Campanian beds, the Eocene limestones take on in places a highly gypseous character. In crossing the hilly tract between the Wadi Teyiba and Gebel Tanka, there appears to be a progressive increase in the proportion of gypsum as the sea is approached.

List of Eocene Fossils.

Determined by M. R. Fourtau from the Author's Collections.

Foraminifera :—

Nummulites gizehensis Ehrenberg, var. *Pachoi* de la Harpe, south of Wadi Baba.

Nummulites of the group *contorta-striata*, mouth of Wadi Teyiba.

Echinoidea :—

Schizaster aff. *vicinalis* Ag., Gebel Tanka.

Vermes :—

Serpula (*Rotularia*) *spirulæa* Defr., south of Wadi Nukhul and east of Gebel Tanka.

Mollusca :—

Pectunculus pyramidarum Opphm., junction of Wadi Shellal and Wadi Baba.

Lucina pharaonum Bell, var. *bialata* Bell, near Gebel Tanka.

Lucina metableta Cossmann, near Gebel Tanka.

Lucina mokattamensis Opphm., near Gebel Tanka.

Cardita Viquesneli d'Arch. and Haime, Near Gebel Tanka and Bir Queisa.

Cytheræa parisiensis Desh., near Gebel Tanka.

Leptothyra gibbula Opphm., near Gebel Tanka.

Collonia grandis Opphm., near Gebel Tanka, and south of Wadi Nukhul.

Turritella cf. *heluanensis* M.-E., near Gebel Tanka and Bir Queisa.

Turritella Lessepsi M.-E., south of Wadi Nukhul.

Turritella pseudo-imbricataria Opp., near Gebel Tanka.

Mesalia Locardi, near Gebel Tanka.

Scalaria aff. *mokattamensis* Opp., near Gebel Tanka.

Heligmotoma niloticum M.-E., near Gebel Tanka.

Cassis ægyptiaca Opphm., near Gebel Tanka.

Cypræa ægyptiaca Opphm., near Gebel Tanka.

Pisces :—

Lamna elegans Agassiz, south of Wadi Nukhul.

Carcharadon auriculatus Blainv., south of Wadi Nukhul.

Myliobatis Pentoni Woodward, south of Wadi Nukhul.

CRETACEOUS.

Campanian.

Campanian strata form the major portion of the extensive tract of white hills which stretches north-westwards from the plain of Markhâ, including the Matulla range and Gebels el Tihia and Gorlos.* They are also a prominent feature round about the mouth of Wadi Baba, and they compose a small group of conspicuous white hills near the head of Wadi el 'Iseila.

Where the whole or nearly the whole of the Campanian beds are exposed, as in the high ridge two kilometres north of Bir el Markhâ (*see* Fig. 14), three divisions are readily recognizable in the field. The lowest division is composed of white chalk containing *Ostrea* (*Gryphæa*) *vesicularis*, var. *proboscidea*. This division is overlain by a series of grey and greenish clays, sometimes with thin chalk bands, in which no fossils have been found. The uppermost of the three divisions, which is the thickest and most important, consists of well-bedded white chalk with flint bands, and at one place contains *Cardita Beaumonti*, var. *depressa*, *Lucina dachelensis*, *Leda perdita*, *Cerithium Reyi*, and other shells. The Campanian typically forms highly dissected hilly country of a dazzling white aspect. The hills are mostly high ridges with narrow crests running in the direction of strike of the beds, having a steep and frequently unclimbable face on one side and a more gradual dip slope on the other. The steeper slopes are commonly highly grooved by multitudes of tiny drainage lines, the chalky rocks being soft enough to be easily eroded, while sufficiently hard not

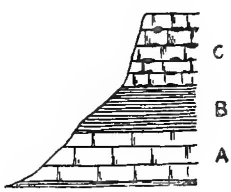

FIG. 14.—Section of the Campanian strata exposed in the hill range two kilometres north of Bir el Markhâ. A, white chalk with *Ostrea vesicularis*; B, grey and greenish clays; C, white chalky limestone with flint beds.

* I have mapped the Matulla range and Gebels Gorlos and Tihia as Campanian, because of their lithological resemblance to the strata of other hills in the district known from fossil evidence to be Campanian, and from their apparent stratigraphical relationships in the field. But I did not get a single fossil from any of these hills, though I ascended them all. I spent a long day on the Matulla range, ascending at its north end and traversing the entire length of its narrow crest to the south peak. The range consists of chalk and limestone overlying clays, and these I believe to be the two upper divisions of the Campanian; but I am not quite sure that there is not a north and south fault running along the eastern foot of the range, and it is just possible that the limestones are Eocene, with the equivalent of the Esna shales below.

to crumble away readily. This grooving, which is well shown in the lower photograph on Plate XVIII, is specially characteristic of the lower beds of the Campanian; the upper flint-banded series is harder and often presents nearly vertical faces. The hills are separated by narrow winding wadis, often shut in by such steep walls of rock as to be veritable canyons, and presenting precipitous steps in their rocky floor.

Fossils are on the whole extremely scarce in the Campanian beds of this part of Sinai. The only fossil found in the lowest of the three divisions, *Ostrea* (*Gryphœa*) *vesicularis*, is very sporadically

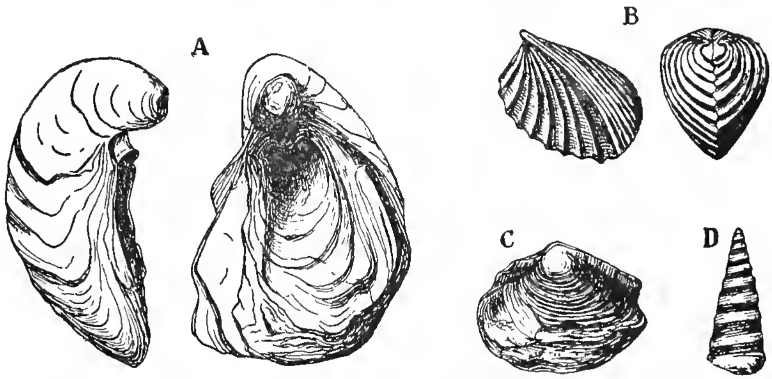

FIG. 15.—Campanian Fossils. A, *Ostrea* (*Gryphœa*) *vesicularis* Lam., var. *proboscidea* Coquand; B, *Cardita Beaumonti* d'Archiac et Haime, var. *depressa*, C, *Lucina dachelensis* Wanner; D, *Turritella* sp.

A is from the head of Wadi el ʿIseila; B, C, and D from a hill on the north side of Wadi Nukhul, three kilometres east of Gebel Matulla.

All the figures are slightly reduced from the natural size.

distributed. It always occurs quite close to the base of the beds, at some points in such numbers as nearly to cover the ground for many yards; but between such points one may search the beds for miles without encountering a single specimen. The fossils of the uppermost division are so scarce that Barron was unable to find a single one, and was consequently unable to determine the precise age of the beds; I have, however, found them in tolerable abundance at one particular spot, *viz.* near the top of the 334-metre hill on the north side of Wadi Nukhul, three kilometres east of Gebel Matulla.

Where the actual base of the Campanian is visible, to the north-west of Bir el Markhâ, the beds conformably overlie the Santonian clays. Where they are overlain by the Eocene, near the mouth of Wadi Nukhul, the junction appears also conformable; but the upper limit is extremely difficult to trace in the field, owing to the almost

identical nature of the uppermost Cretaceous beds and the lowest Eocene ones, combined with the scarcity of fossils in both formations.

At some places, especially in and near the Matulla range, the upper Campanian limestones are highly gypseous. I could not ascertain whether the gypsum was a primary deposit, or the result of a later alteration of the limestones ; but I incline to the former view. Where gypsum occurs in the clays, it is mostly as veins, and here it has certainly been deposited after the beds were formed, doubtless by solution from the overlying calcareous beds.

At certain points, notably in the Wadis Nukhul and Teyiba, the Campanian limestones are blackened by the presence of hydrocarbons. These occurrences are invariably in the immediate neighbourhood of volcanic intrusions, and are evidently the result of natural distillation from deeper lying strata.

An accurate estimate of the total thickness of the Campanian is almost impossible, partly owing to the difficulty of drawing a line between it and the overlying Eocene, but chiefly on account of the folded and faulted structure of the country. I am inclined to think Barron's estimate of 500 metres* may be rather high, because there are folds up and down as one goes eastwards to Sarbut el Gamal, and some of the beds which Barron thought to belong to this division are now proved to be Eocene ; but the total thickness is almost certainly over 300 metres. The greatest thickness observable in a single exposure is about 260 metres in the high ridge two kilometres north of Bir el Markhâ, where the base is clearly marked, but the top of the series is probably not seen.

List of Campanian Fossils.

Collected by the Author and Determined by M. R. Fourtau.

Mollusca :—

Ostrea (*Gryphæa*) *vesicularis*, var. *proboscidea* Coq., head of Wadi el 'Iseila and north of Bir el Markhâ.

Leda perdita Conrad, and var. *Sinæa* Fourtau, 334-metre hill, north of Wadi Nukhul.

Lucina dachelensis Wanner, north of Wadi Nukhul.

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* "Western Sinai," p. 147.

Cardita Beaumonti d'Arch. et Haime, var. *depressa*, d'Archiac and Haime, north of Wadi Nukhul.
Cerithium Reyi Lartet, north of Wadi Nukhul.
Scalaria sp., north of Wadi Nukhul.
Turritella sp., north of Wadi Nukhul.

Santonian.

The presence of Santonian beds in this part of Sinai has been established at only one locality, *viz.* to the north-west of Bir el Markhâ, where they form a triangular area composed of low hills. The beds consist of yellow-brown clays with some limestones, from which the little sea-urchin *Echinobrissus Waltheri*, and the characteristic oysters *Ostrea dichotoma* and *Ostrea Nicaisei* (Fig. 16) were obtained, as well

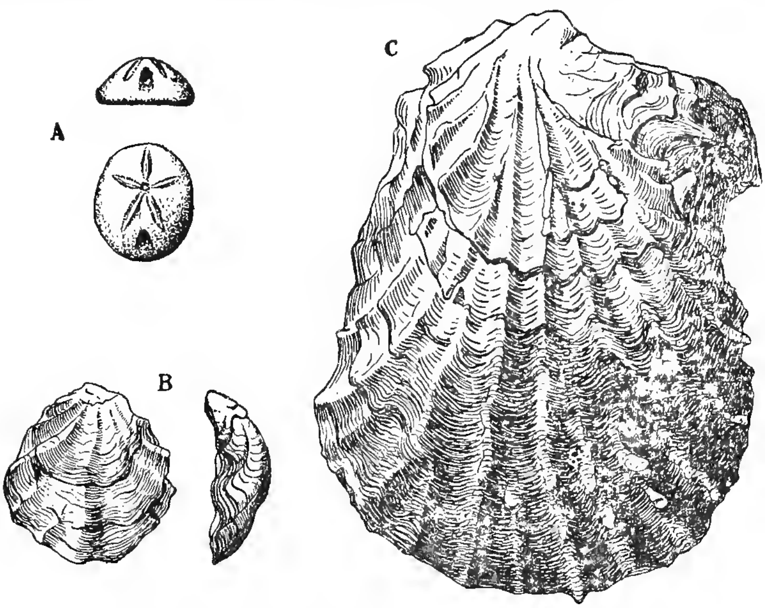

FIG. 16.—Santonian Fossils. A, *Echinobrissus Waltheri* Gauthier; B, *Ostrea* (*Alectryonia*) *Nicaisei*, race *Pomeli* Coquand; C, *Ostrea* (*Alectryonia*) *dichotoma* Bayle. All slightly less than the natural size.

as sharks' teeth. At the top, the beds are conformably overlain by the Campanian chalk. The base is not visible, as the beds are cut off to the west by a fault against the Eocene and Miocene, as shown in Figure 10 on page 126. The exposed thickness is probably over 100 metres.

List of Santonian Fossils.

Determined by M. R. Fourtau in the Author's Collections.

Echinoidea :—

Echinobrissus Waltheri Gauthier, north of Bir el Markhâ.

Mollusca :—

Lima sp., north of Bir el Markhâ.

Ostrea Bourguignati Coquand, north of Bir el Markhâ.

Ostrea dichotoma Bayle, and var. *acanthonota* Coquand, north of Bir el Markhâ.

Ostrea Nicaisei Coq., race *Pomeli* Coq., north of Bir el Markhâ.

Trigonia scabra Lamarck, north of Bir el Markhâ.

Turonian.

The existence of Turonian strata in Sinai had hitherto been a a matter of some doubt, Duncan having considered that there were grounds for believing the Turonian to be present, while Rothpletz took the contrary view.* The question is almost entirely a palæontological one, and the uncertainty was due to the insufficiency of the fossil collections to decide the point. But amongst the very large assemblage of Cretaceous fossils collected by the author, Mr. Fourtau has identified a number of typically Turonian forms from the uppermost beds of the Tih escarpment and from Gebel Abu 'Edeimat, and he considers that these afford an absolute proof that the Turonian not only exists, but that it covers a considerable area in this part of Sinai, extending in fact almost all along the top of the Tih escarpment and likewise capping the hill masses of Gebels Abu 'Edeimat and 'Iseila, while a small patch also occurs on the summit of Gebel Musaba' Salâma. The Turonian stage is in reality merely a series of passage beds between the Cenomanian and the Santonian, and here as elsewhere it is extremely difficult to define its limits. With the upper limits we are not so much concerned, as no exposure has been met with where the Turonian is superposed by the Santonian in this part of Sinai. For the lower limit, M. Fourtau regards the incoming of

* *See* Barron's "Western Sinai," p. 151.

echinoids of the genus *Cyphosoma* as marking the horizon; and consequently the upper boundary of the Cenomanian must be taken below the level at which this particular form occurs, though many of the fossils present in the Cenomanian persist above this limit. In tracing the boundary between the Turonian and Cenomanian in the field, it was not of course possible to search every yard of the miles of exposure for fossils, and consequently it was desirable if possible to discover some lithological peculiarity which marked the boundary and which could be easily followed. At the place where the Tih escarpment was first ascended, near Gebel Sâlia, no marked lithological peculiarity presented itself, though it was noticed that *Cyphosoma* only occurred at or near the top of the scarp; and the scarp is so steep that no sensible error can have resulted in the mapping by carrying the boundary along it just below its top. In the neighbourhood of Gebel Shushet Abu el Nimran the scarp becomes somewhat broken, and the Turonian beds are cut through into isolated patches capping the higher parts. From Gebel Ras Um Qatafa north-westwards to Gebel Ras el Hemeitia, a persistent bed of sandstone, about eight metres thick, near the top of the scarp above the Cenomanian limestone and clays, forms a prominent feature, making a sort of platform from which rise hills of limestone. As *Cyphosoma* and the other fossils specially characteristic of the Turonian appear to be confined to the beds overlying the sandstone, while the typically Cenomanian forms, such as *Holectypus Larteti* and *Ostrea Mermeti*, occur only below it, the base of the sandstone-bed is conveniently taken as marking the limit between the Cenomanian and Turonian in this stretch of the scarp. Frequent landslips have let down the sandstone-bed locally, and it is usually separating in large masses by great cracks parallel to the free edges.

Except for the basal sandstone-bed above referred to, the Turonian strata of Gebel el Tih consist entirely of limestones, white to brown in colour and varying considerably in hardness. The bedding is nearly horizontal, and conformable to the underlying Cenomanian. Though the upper limit of the beds was nowhere seen, a secondary scarp of very white aspect could be observed to rise from the broken plateau surface some distance back from the main scarp, and this probably consists of Campanian beds; the Santonian, if it exists hereabouts, would not be readily visible, as it would lie at the foot of the white

secondary scarp, and the irregularities of the ground prevented the foot of the scarp being seen. The thickness of the Turonian on Gebel el Tih is probably about 100 metres, perhaps a little more.

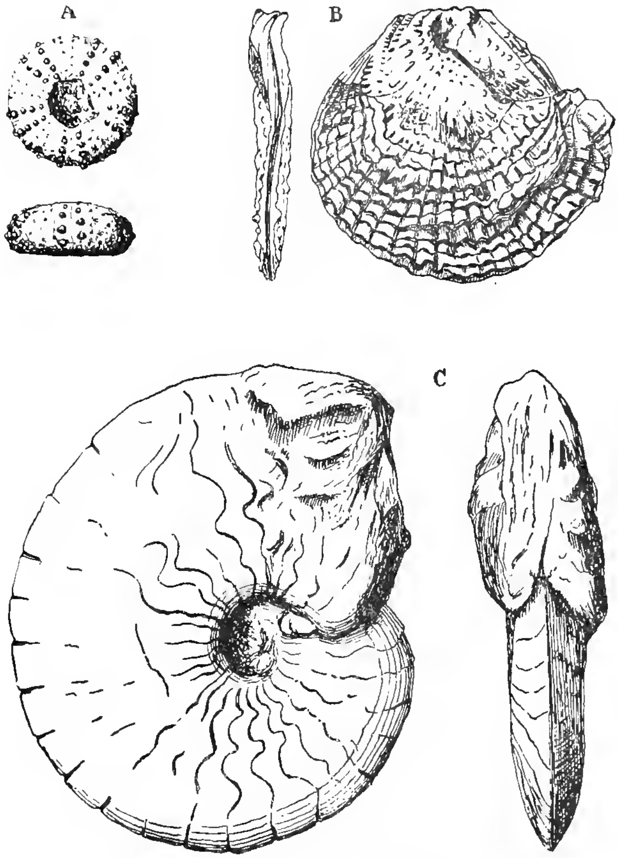

FIG. 17.—Turonian Fossils. A, *Cyphosoma Baylei* Cotteau: B, *Plicatula Ferryi* Coquand, C, *Leoniceras segne* Solger. A and C are from Gebel el Tih: B from Gebel Abu ʿEdeimat. All the figures are slightly less than the natural size.

Besides the *Cyphosoma* above referred to (*see* Fig. 17), the Turonian beds are specially characterized by the abundance of ammonites of the *Leoniceras* type. This particular specimen figured is a very small one; others of much larger size, up to thirty centimetres or so in diameter, were frequently met with, though generally in fragments. The mollusc *Plicatula Ferryi*, though here only met with in the Turonian, extends elsewhere upward into the Senonian, and is thus less characteristic than the other forms.

The Turonian beds of Gebels Abu ʿEdeimat, ʿIseila, and Musabaʿ Salâma resemble those of Gebel el Tih, but are somewhat thinner and are considerably tilted. In the upper part of Wadi Abu Insakar, the Turonian appears to have been brought down by a fault to the same level as the Nubian sandstone.

List of Turonian Fossils.

Identified by M. R. Fourtau from the Author's Collections.

Echinoids :—

Cyphosoma Baylei Cotteau, Gebel el Tih.
Cyphosoma majus Coquand, Gebel el Tih.
Hemiaster Balli Fourtau, Gebel el Tih.

Mollusca :—

Plicatula Ferryi Coquand, Gebel Abu 'Edeimat.
Tylostoma globosum Sharpe, Gebel el Tih.
Tylostoma Peroni Pervinquière, Gebel el Tih.
Thomasites Rollandi Thomas and Peron, Gebel el Tih.
Leoniceras segne Solger, Gebel el Tih.

Cenomanian.

The Cenomanian is represented in West-Central Sinai by a series of limestones, marls, and clays, some 200 metres in total thickness, lying conformably between the Nubian sandstone below and the Turonian strata above. The beds are magnificiently exposed along the Tih escarpment, though the slopes are mostly obscured by debris. A section of the scarp close west of Gebel Sâlia is shown in Figure 18. The lower half of the series consists of yellowish, greyish, and greenish clays, in which fossils are not frequent. This is succeeded by about a hundred metres of marls and limestones, in which fossils are abundant. As will be seen from the geological map on Plate I, a dolerite sheet extends for over eight kilometres along the scarp in the neighbourhood of Gebel Sâlia, separating the base of the Cenomanian clays from the Nubian sandstone; but that this igneous sheet is of later date than the beds between which it occurs is clearly proved by a dyke from it cutting up

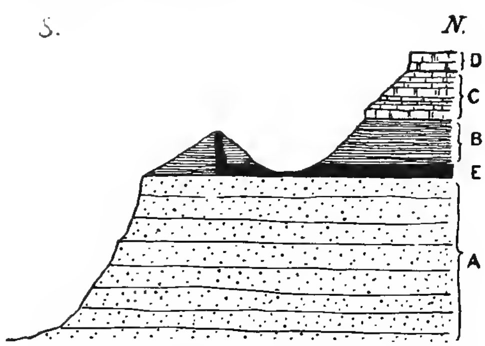

Fig. 18.—Section through the Tih escarpment west of Gebel Sâlia. A, Nubian sandstone; B, lower portion of the Cenomanian, consisting chiefly of clays; C, Upper Cenomanian beds, mainly limestones and marls; D, Turonian limestones; E, dolerite sheet, intrusive.

vertically through them at one place. Another doleritic intrusion into the Cenomanian occurs in the face of the Tih plateau near Gebel Shushet Abu el Nimran, and here the limestone has been altered at the contact into a black crystalline form.

Besides the exposures at the face of the Tih escarpment, the Cenomanian beds are also well seen where cut through by the steeply falling heads of the wadis draining north-westwards from the scarp, as well as on the slopes of Gebels Abu 'Edeimat, 'Iseila, and Musaba' Salâma, at all of which places they show the same general characters. And at intervals along the great fault which runs southward through Gebel Musaba' Salâma and across the Wadi Baba, the pinched out beds close to the fault include parts of the Cenomanian.

To the north of the district mapped in detail, the Cenomanian strata cover a great extent of the broken plateau of El Tih, and are well exposed on both sides of the Wadi Abu Qâda. In the Wadi Thal at Bir Qattar the Cenomanian contains a remarkable bed of hard dark grey crystalline limestone, of the same type as that found elsewhere as the result of contact metamorphism by intrusive dolerite; but I did not see any igneous rock in this particular locality.

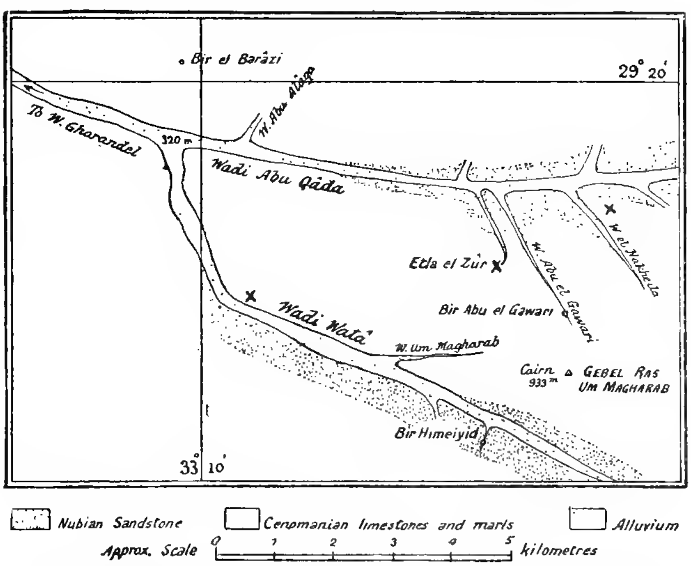

FIG. 19.—Sketch map of the Wadi Abu Qâda district, showing the localities where oil marls and coal shales occur. Outcrops of oil marls are indicated by crosses. A thin seam of coal exists at Bir Himeiyid.

In the upper reaches of the Wadi Abu Qâda certain of the marl beds contain hydrocarbons in the form of oily and asphaltic matter.

The sketch map in Figure 19 shows the places where these hydrocarbon-bearing marls have been observed.

At Etla el Zur, there are a number of exposures of the oil-bearing marls round the sides of a small amphitheatre which forms the head of a short steep wadi. A measured section of the lowest and most northerly exposure is shown in Figure 20; it will be seen that three beds of the oil marls are here exposed, having a total thickness of ninety-five centimetres. The oil marl is a very compact rock, of a dark brown to nearly black colour, about as hard as chalk rock, and breaking with a sub-conchoidal fracture. The oil marl beds are pretty sharply marked off from the intervening limestones and marls; no stratification or lamination is usually visible in the oil-bearing beds themselves, which but for their dark colour and hydrocarbon contents would be described as thickly bedded compact chalk or chalk marl. When the oil marl is put on a fire, it decrepitates, stinks, and sometimes gives off inflammable gas. Analyses of the three beds figured in the above section show the bottom, middle, and top beds to contain respectively 1·04, 1·63, and 1·08 per cent of volatile oily and asphaltic matter. These beds appear to extend for a long distance, but the outcrops are so obscured by debris that it is difficult to follow them continuously. Higher up the scarp of the amphitheatre there are other similar beds of greater thickness, but these show the dark colour only in places, and the hydrocarbons may thus be confined to particular patches; but possibly the patchy appearance is only due to weathering of the exposed face. Analyses of three typical specimens from these upper beds gave respectively 1·80, 0·33, and 1·37 per cent of volatile organic matter.

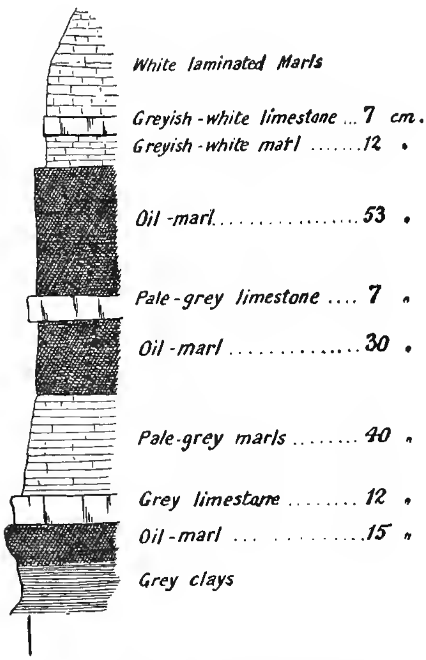

FIG. 20.—Section of Oil-marl strata, Etla el Zur.

The geological horizon of the oil-bearing beds is accurately fixed by the finding of *Ostrea* (*Exogyra*) *olisiponensis* in the clays just below them, proving their Cenomanian age; the top of the Nubian sandstone was found to be about 125 metres below the oil marls at Etla el Zur.

I did not find time to visit the exposures further east, near the Wadi el Nakheila, but a guide sent to the place brought back rocks exactly similar to those of Etla el Zur. Analysis of two specimens gave respectively 1·40 and 1·43 per cent of total volatile oily and asphaltic matter. There can, I think, be little doubt that the beds at Wadi el Nakheila are at the same geological horizon as those of Etla el Zur, and may be continuous with them. To be certain as to continuity would, however, require careful tracing of the outcrops along the steep debris-covered scarps.

The occurrences of oil marls at Etla el Zur and Wadi el Nakheila appear to be independent of volcanic action, as no intrusions of igneous rock were visible in their vicinity. The field appearances were, so far as I could judge, all in favour of the oil having been formed in the marls themselves. But at the bend in Wadi Abu Qâda (*see* sketch map Fig. 19) I noticed hydrocarbons were most strongly

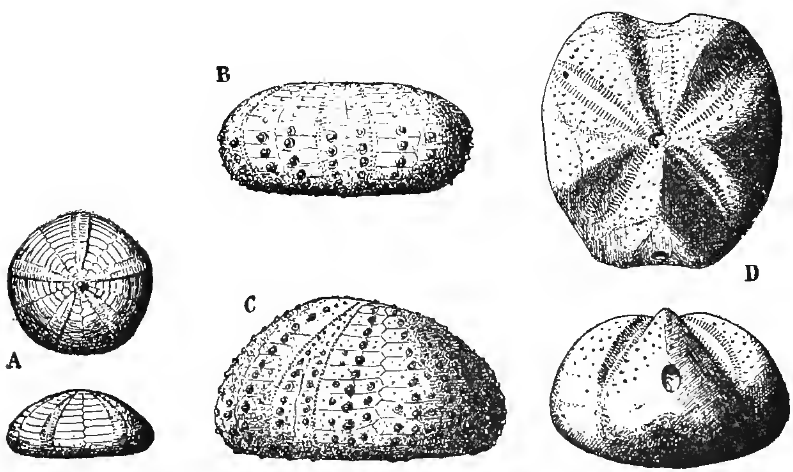

FIG. 21.—Cenomanian Echinoids. A, *Holectypus Larteti* Cotteau, Wadi Abu Qada; B, *Heterodiadema libycum* Desor, Gebel el Tih; C, *Orthopsis Ruppelii* Desor, Gebel Abu ʿEdeimat; D, *Hemiaster Heberti* Coquand, Gebel Abu ʿEdeimat. All the figures are slightly less than natural size.

evident in the marls in the immediate neighbourhood of a great doleritic intrusion, and here at least it seems impossible to doubt

that volcanic action has in some way conditioned the present distribution of the oily matter. It is easy to conceive that the upper part of a basaltic intrusion would cool before the deeper portion, and oil

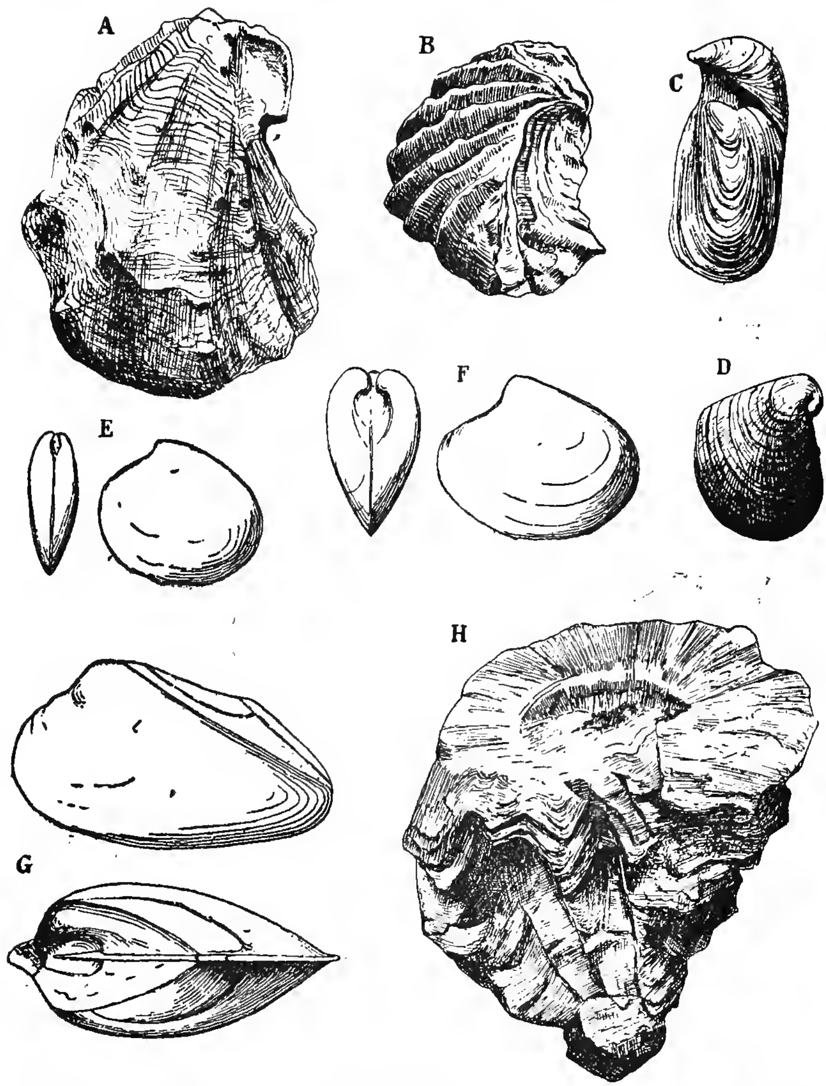

FIG. 22.—Cenomanian Lamellibranchiata. A, *Ostrea (Exogyra) olisiponensis* Sharpe; B, *Ostrea (Exogyra) flabellata* Goldfuss; C, *Ostrea (Exogyra) africana* Lamarck; D, *Ostrea (Exogyra) Mermeti* Coquand; E, *Dosinia Delettrei* Coquand; F, *Venus Reynesi* Coquand; G, *Arca Coquandi* Fourtau; H, *Eoradiolites sinaiticus* Douvillé.

B, from Gebel Abu ʿEdeimat; H, from Wadi Abu Qâda; the others from Gebel el Tih. All the figures are slightly less than the natural size.

distilled from the lower strata cut through by a dyke might thus condense in higher beds, where the temperature was lower.

From the small hydrocarbon content (averaging 1·2 per cent) of the oil marls, it is apparent that, even allowing for a reasonably greater proportion in the interior of the beds as compared with the weathered portions which were alone examined, these beds are not in themselves of any economic value as a possible source of oil. But they are of interest in their possible bearing on the origin of oil in the Gulf of Suez; this point will be discussed in dealing with the physical geology of the region in the next chapter.

The Cenomanian beds are so rich in characteristic fossils that there is seldom any doubt about their recognition in the field, even in places where their stratigraphical relationships are obscured by debris or by faulting. Not only are the Cenomanian fossils abundant as individuals, but they include a large number of genera and species; a complete list of those collected will be found on page 145. Among the sea-urchin fauna (*see* Fig. 21) the small *Holectypus Larteti* is a very frequent form, and is easily recognized by the circumferential striation resulting from the slight separation of its plates by weathering. Of the numerous species of the genus *Hemiaster*, *H. Herberti* is one of the commonest. The oysters of this division of the Upper Cretaceous (*see* Fig. 22) are even more abundant and characteristic than the echinoids, the exogyrate forms *O. Mermeti*, *O. africana*, and *O. flabellata* being very common and easily recognized. The thick-shelled *Eoradiolites sinaiticus*, though not very abundant, is absolutely characteristic of the uppermost Cenomanian beds, as also are *Nerinæa bicatenata* and *N. olisiponensis* (Fig. 23). The practicable tracks up and down the scarps pass commonly over the more easy slopes, which are naturally the most littered with debris, so that the fossils of the different zones are liable to get mixed up; but enough was seen to be sure that *Eoradiolites* and *Nerinæa* are confined to near the top of the series, while the various echinoids and exogyras are more abundant at lower levels. It may be

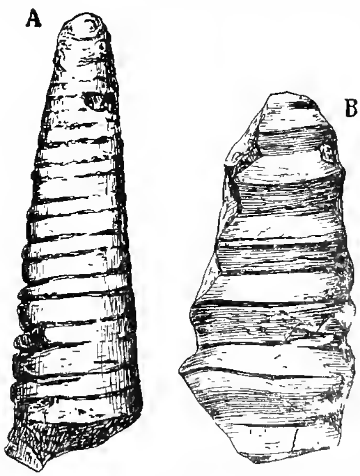

FIG. 23.—Cenomanian Gasteropoda. A, *Nerinæa olisiponensis* Sharpe, from Gebel Ras el Hemeitia; B, *Nerinæa bicatenata* Coquand, from Gebel Abu 'Edeimat. Both slightly reduced from natural size.

remarked here that two fine specimens of *Ostrea Mermeti* were brought up from a depth of about 700 metres in one of the oil borings at Gebel Tanka, proving the Cenomanian to exist there.

List of Cenomanian Fossils.

Determined by M. R. Fourtau from the Author's Collections.

Echinoids :—

Leiocidaris Balli Fourtau, Gebel Beit Salâma.

Pseudodiadema bigranulatum Gregory, Wadi Abu Qâda.

Diplopodia marticensis Cotteau, Wadi Abu Qâda.

Heterodiadema libycum Desor, Gebel el Tih, north of Sarbut el Gamal ; Wadi Abu Qâda.

Orthopsis Ruppelii Desor, Gebel el Tih, Gebel Abu ʿEdeimat.

Orthechinus quincuncialis Greg., Gebel el Tih, Wadi Abu Qâda.

Holectypus cenomanensis Guéranger, Gebel el Tih.

Holectypus Larteti Cotteau, Wadi Abu Qâda.

Holectypus Larteti race *sinæa* Fourtau, Gebel el Tih, Wadi Abu Qâda.

Holectypus Larteti, var. *Dowsoni* Fourtau, Wadi Abu Qâda, Gebel Musabaʿ Salâma.

Holectypus pulvinatus Desor, Gebel el Tih, Gebel Abu ʿEdeimat, Wadi Abu Qâda.

Echinobrissus Balli Fourtau, Gebel el Tih.

Hemiaster batnensis Coquand, Gebel Abu ʿEdeimat.

Hemiaster aff. *Bourguignati* Coq., Gebel el Tih, Gebel Abu ʿEdeimat.

Hemiaster cubicus Desor, Gebel el Tih, Gebel Abu ʿEdeimat, Gebel Musabaʿ Salâma.

Hemiaster Gabrielis Peron and Gauth., var. *ægyptiaca* Fourtau, Wadi Abu Qâda.

Hemiaster Heberti Coquand, Wadi Abu Qâda, Gebel Abu ʿEdeimat.

Hemiaster Heberti var. *Artini* Gauth., Gebel el Tih, Gebel Abu ʿEdeimat, Ras el Gawari.

Hemiaster Heberti, var. *Coquandi* Seg., Gebel Abu ʿEdeimat.

Hemiaster latistella Fourtau, Gebel el Tih.

Hemiaster numidicus Gauthier, Gebel el Tih.

Hemiaster Meslei Peron and Gauth. and var. *oblonga* Fourtau, Gebel el Tih, north of Gebel Sarbut el Gamal.

Hemiaster oblique-truncatus Peron and Gauth., race *orientalis* Fourtau, Gebel el Tih.

Hemiaster pseudofourneli Peron and Gauth., Gebel el Tih, Wadi Abu Qâda.

Hemiaster proximus Fourtau, Gebel el Tih.

Hemiaster aff. *proclivis* Peron and Gauth., Wadi Abu Qâda.

Hemiaster sp. ind., Wadi Abu Qâda.

Linthia Balli Fourtau and var. *expansa* Fourtau, Gebel el Tih.

LAMELLIBRANCHIATA :—

Arca Coquandi Fourtau (=*Arca parallela* Coq. non Conrad), Gebel el Tih.

Avicula cf. *Delettrei* Coquand, Gebel el Tih.

Avicula aff. *gravida* Coquand, Gebel el Tih.

Avicula mytiloides Coquand, Gebel el Tih, Gebel Abu 'Edeimat.

Modiola ornatissima d'Orbigny, Gebel el Tih.

Plicatula auressensis Coquand, Gebel el Tih, Gebel Abu 'Edeimat.

Pecten alpinus d'Orbigny, Gebel el Tih.

Lima cf. *Grenieri* Coquand, Gebel el Tih.

Ostrea africana Lamarck, Gebel el Tih, Gebel Abu 'Edeimat, Wadi Abu Qâda.

Ostrea Delettrei Coquand, Gebel Abu 'Edeimat.

Ostrea flabellata Goldfuss, Gebel el Tih, Gebel Abu 'Edeimat, Wadi Abu Qâda.

Ostrea Mermeti Coquand, Gebel el Tih, Wadi Abu Qâda.

Ostrea olisiponensis Sharpe and var. *pseudo-africana* Choffat, Gebel el Tih, Wadi Abu Qâda.

Nayadina Gaudryi Thomas and Peron, Wadi Abu Qâda.

Cyprina cordata Sharpe, Gebel el Tih, Gebel Abu 'Edeimat.

Anisocardia aquilina Coquand, Gebel el Tih.

Cardita Forgemoli Coquand and numerous varieties, Gebel el Tih Gebel Abu 'Edeimat.

Cardium aff. *Mermeti* Coquand, Wadi Abu Qâda.

Protocardia Combei Lartet, Gebel el Tih.

Dosinia Delettrei, Coquand, Gebel el Tih.

Venus Cleopatra Coquand, Gebel el Tih.
Venus Fatma Coquand, Gebel Abu 'Edeimat.
Venus mauritanica Coquand, Gebel el Tih.
Venus Reynesi Coquand, Gebel el Tih.
Panopæa cf. *astieriana* d'Orbigny, Gebel el Tih.
Corbula navis Choffat, Wadi Abu Qâda.
Eoradiolites Davidsoni Hill, Gebel el Tih.
Eoradiolites sinaiticus Douvillé, Wadi Abu Qâda.

GASTEROPODA :—

Natica Letourneuxi Coquand, Gebel el Tih.
Natica sp., Gebel el Tih.
Aporrhais portentosa Coquand, Gebel el Tih.
Apporrhais aff. *Peini* Coquand, Gebel Ras Um Qatafa.
Aporrhais sp., Gebel el Tih.
Strombus incertus d'Orbigny, Gebel el Tih.
Strombus inornatus d'Orbigny var. *Mermeti* Coquand, Gebel el Tih.
Globiconcha ponderosa Coquand, Gebel Abu 'Edeimat.
Pterodonta Deffisi Thomas et Peron, Gebel Abu 'Edeimat.
Cerithium tenouklense Coquand, Gebel el Tih.
Nerinæa bicatenata Coquand, Gebel Abu 'Edeimat.
Nerinæa olisiponensis Sharpe, Gebel Ras el Hemeitia.
Cassidaria aff. *Heinzi* Coquand, Gebel Abu 'Edeimat.

CEPHALOPODA :—

Nautilus sp., Gebel el Tih.
Neolobites Schweinfurthi Eck., Gebel el Tih.
Schloenbachia sp., Gebel el Tih.

NUBIAN SANDSTONE.

Between the base of the Cenomanian clays and the top of the Carboniferous limestone there exists in this part of Sinai a huge thickness (some 650 metres) of sandstones, conformable, so far as has been observed, with the beds both above and below them. Only the lower 150 metres or so have been found to contain any fossils, and these are almost entirely the remains of Carboniferous trees of the *Lepido-*

dendron type. For the lower 150 metres of the sandstones, that is, the portion which comes immediately above the Carboniferous limestone, a Carboniferous age is thus clearly indicated; and this portion is conveniently named the *Upper Carboniferous sandstone*. I shall here define the term "Nubian sandstone" to signify the thickness of 500 metres or so of unfossiliferous sandstone, lying between the Upper Carboniferous sandstone and the base of the Cenomanian clays, not including in it either the lower beds which contain *Lepidodendron*, as has been done by some writers on Sinai, nor the detached sandstone beds of Turonian age which are interbedded in the Upper Cretaceous limestone series, as has been done by Dr. Hume* for similar beds in Egypt.

Nubian sandstone forms the lower half of the great scarp of El Tih from Gebel el Hemeitia eastwards to far beyond Gebel Rueikna, and extends southwards across the lower hill tract to the sandy plain of Debbet el Qeri. It also occurs in the Wadi Thal a little below its head, and in the upper feeders of Wadi Gharandel. On the south-east flank of Gebel Abu ʿEdeimat the Nubian sandstone crops out from under the Cenomanian, and thence extends southwards as a narrow band flanking Gebels Sarbut el Gamal and Musabaʿ Salâma on their eastern sides, being limited to the west by the great fault which has thrown it up alongside the Campanian and Miocene strata. A very small exposure of Nubian sandstone likewise occurs to the south of Gebel Samrâ, where it crops out from under the Cenomanian between two faults.

The Nubian sandstone is a medium-grained rock resembling the Triassic sandstone of England, varying in colour at different places from nearly white to various shades of brown, red, and purple. In the great mass which extends southward from Gebel el Tih, the bedding planes of the rock dip very gently to the north, but near the great fault there has been strong tilting of the beds. False bedding is often seen, and the rock contains some dark ferruginous bands, usually, however, thin and of limited extent. To the east of Wadi el Muqafa the sandstones pass into coarse grits, and even into conglomerates like those found at the base of the Nubian sandstone at

* Hume, "Secular Oscillation in Egypt." Q.J.G.S. 1911, p. 121; and "Explanatory Notes to accompany the Geological Map of Egypt," Cairo, 1912, p. 29.

Aswân and elsewhere in Egypt. Near the head of Wadi Muqafa I picked up the only fossil which I have found in the Nubian sandstone of Sinai, a piece of silicified wood, similar to that which occurs in the Nubian sandstone of Egypt.

Where the sandstone has been invaded by basaltic intrusions it is generally altered to a hard quartzite for a metre or so on either side.

A very interesting local variation in the Nubian sandstone occurs close to Bir Himeiyid (see page 103, and the maps on Plate XV, and Fig. 19, page 140), in the shape of a thin seam of black carbonaceous shale with some true coal. The shale crops out on either side of the little gully in which Bir Himeiyid is situated. A section is shown in Figure 24. The carbonaceous seam, which contains yellow strings (sulphur ?), is about twenty-five centimetres thick, overlain by sandstone and underlain by grey shales. I excavated about twenty kilogrammes of the more coaly part of the shale with a pick, and tried to make a fire of it, with only partial success; the stuff would burn when well started with a charcoal fire and continuously blown, but left to itself it merely smouldered away, leaving a great deal of ash. An analysis of a sample sent to the Survey Department Laboratory yielded the following results :—

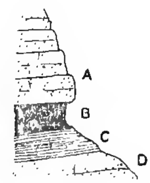

FIG. 24.—Section of carbonaceous shale in the Nubian sandstone at Bir Himeiyid. A, Sandstone; B, Carbonaceous shale; C, Grey shales.

Moisture	21·48	per cent.
Combustible substance :—		
Volatile matter...	26·52	,,
Coke	31·83	,,
Ash	20·17	,,
	100·00	,,

The calculated calorific value was 5,342 calories per gramme, or 9,615 British thermal units per pound. It is obvious from these figures that the coal is of very poor quality. Even had it been otherwise, the seam is too thin and of too slight an extent to be of more than scientific interest. The exposure can only be traced for a few metres, and the deposit is probably only a small lenticular mass due to a local accumulation of vegetable matter in the sandstone. I fancied I detected a reed-like impression in the coal at one place, but could not

be certain. The horizon of the shales is 150 metres below the top of the Nubian sandstone.

Apart from colour changes and the local variations above referred to, the Nubian sandstone is, on the whole, remarkably homogeneous throughout its great thickness of 500 metres or more. Its upper limit is everywhere very sharply marked by its contrast with the overlying Cenomanian clays and marls, while in addition its greater hardness as compared with the overlying rocks causes it frequently to form a sort of flanking platform round Gebel el Tih, the sandstone portion of the scarp often presenting vertical drops of nearly a hundred metres, while the clays above fall back with a slope of some 30° to 40°.

The lower limit of the Nubian sandstone is much less easily traceable; for no unconformity nor any marked difference in the character of the beds mark them off as a rule from the Upper Carboniferous sandstones below them, and the only criterion for the separation consists of the finding of *Lepidodendron* stems in the Carboniferous. On the whole, the Nubian beds are less red in colour than the Carboniferous sandstones, but there are so many variations of colour in both series that this is a very uncertain guide at any one place. The sheet of basalt, which Barron* imagined to mark the close of the Carboniferous period, has proved on further investigation to be a much later intrusion, probably Miocene; for though at the places where Barron examined it the sheet does approximately mark the upper limit of the *Lepidodendron* flora, at other places it has penetrated into rocks at much higher horizon, and cannot therefore be relied on as a guide.

As to the age of the Nubian sandstone in Sinai, there still remains much doubt. With the exception of a few fragments of silicified wood, no fossils have been found in all the vast mass. The similarity of these fragments of silicified wood to those found in the Nubian sandstone of Egypt, in places where its Upper Cretaceous age is fairly established, and the absence of unconformity between the sandstone and the overlying Cenomanian clays and limestones, are so far in favour of an Upper Cretaceous age, at least for the uppermost portions of the series. But fossil wood is not a very reliable criterion of age, and there is also the fact that the lower beds appear to be just as conformable to the underlying Carboniferous series as the upper ones

* "Western Sinai," p. 163.

are to the Cenomanian. Perhaps the most rational view to take of the age of the Nubian sandstone of this region, on the evidence at present available, is to regard it as representing the whole series of formations from the close of the Carboniferous to the commencement of the Cenomanian. On this view the district must have been low-lying flat ground, subject to alternations of uplift and subsidence without folding, throughout a vast period, being at one time possibly a wind-swept desert, and at another a shallow estuary or sea over the floor of which the sand was redistributed by water. Part of it may thus be of the same age as the Jurassic deposits recently discovered by M. Couyat Barthoux in the northern portion of the peninsula.

CARBONIFEROUS.

The Carboniferous strata of Sinai fall into three well marked divisions :—

1. The *Upper Carboniferous sandstone*, about 150 metres thick, characterized by fossil trees of the *Lepidodendron* type and containing some thin clayey and carbonaceous bands.

2. The *Carboniferous limestone*, about forty metres thick where best developed ; this varies in character from hard crystalline dolomite to soft limestones with earthy and sandy beds; it contains numerous corals, encrinite stems, a considerable variety of characteristic brachiopods, and palatal teeth of selachian fishes.

3. The *Lower Carboniferous sandstone*, about 130 metres thick, poor in fossils, but sometimes showing worm tracks and other organic impressions of which the origin is obscure.

The Upper Carboniferous Sandstone.

The Upper Carboniferous sandstone forms the tract of high ridges which strike north-north-west to the east of Gebels Sarbut el Gamal and Musabaʿ Salâma. From here it extends south-eastwards across the heads of Wadi Khaboba, covering the broken plain of El Qôr, and stretches across Gebel Hazbar eastwards to the hills round Wadi Budaʿ, as well as south-eastwards to Gebel Farsh el Azraq and across the Wadi Sâhu. It caps Gebel Nukhul, and forms other hills rising from the limestone plateaux to the west of El Qôr and round about

the Um Bogma mines. It caps many of the higher mountains of the Shellal basin, such as Gebels Um Riglein, Sarabit el Khâdim, ʽAdeidia, and Moneiga, and forms the principal rock in the highly faulted tract round Wadi Abu Natash.

The Upper Carboniferous sandstone is typically reddish brown in colour, of rather fine grain and moderate hardness; but some of the beds are almost snow white in colour and very friable. It weathers on exposed surfaces into curious hollowed forms, and often gives rise to very rough treacherous ground to walk or climb over, owing to the giving way under foot or in the hand of thin shell-like crusts which partially cover the hollows. The upper beds contain at several places thin bands of white to grey clays and red to purple sandy shales. Associated with the clays a thin carbonaceous band was observed to the south-east of Gebel el ʽIseila, where the northern Wadi el Muqâfa enters Wadi Abu Insakar, and also in the hills east of Bir Nukhul and round the head of Wadi Abu Hish. I did not ascertain if the band was continuous between these places, as it is not conspicuous in the field, being frequently weathered to a whitish colour on exposed surfaces, and the blackness of the interior is only seen on digging a hammer into it; but I am inclined to think that all the occurrences of this carbonaceous clay band are at one horizon, very near to the top of the Carboniferous series.

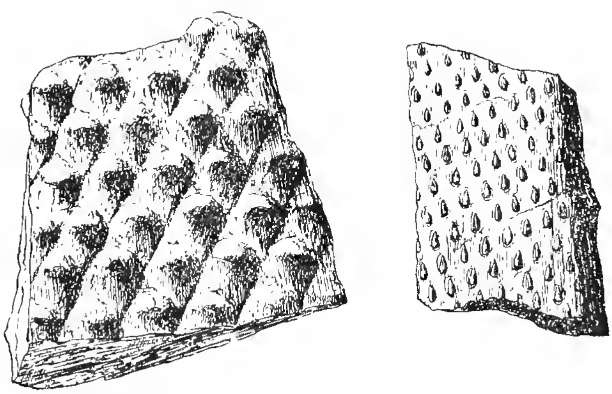

FIG. 25.—Remains of fossils trees (*Lepidodendron*) from the Upper Carboniferous sandstone, Wadi Um Shebba.

Where the sandstone has been intruded by basalt and dolerite, as at Gebel Farsh el Azraq and elsewhere, it is generally hardened to quartzite at the contact; and as Barron has remarked, it is sometimes possible to trace the former presence of basalt sheets in places where the igneous rock has been entirely denuded away and the hardened sandstone left.

The characteristic fossils of the Upper Carboniferous sandstone are the remains of trees of the *Lepidodendron* type (Fig. 25). They

are by no means abundant; the principal finds were made in the Wadi Um Shebba, to the north-east of Gebel Musabaʿ Salâma; fragments of woody tissue were also obtained from the sandstone on the south side of Wadi el Hommur, where it passes between Gebels Sarbut el Gamal and Musabaʿ Salâma. The fragments of *Lepidodendron* are portions of stems up to twenty centimetres in diameter, and have been found up to fifty centimetres or more in length; no approximation to a complete tree has been seen, the remains having the appearance of drifted fragments. Besides the plant remains, one occasionally comes across worm tracks and medusoid markings, while ripple-mark is often well preserved.

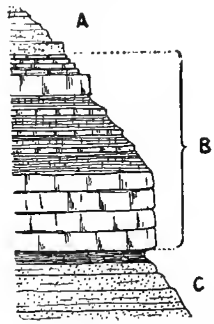

FIG. 26.—Section of the Carboniferous limestone series, Gebel Nukhul. A, Upper Carboniferous sandstone; B, Carboniferous limestone series; C, Lower Carboniferous sandstones, with a thin band of brown and green sandy clays at the top.

Owing to the difficulty of tracing the upper limit of the beds, the thickness of the Upper Carboniferous sandstone cannot be very exactly estimated; it is at least 150 metres, and may be considerably more.

The Carboniferous Limestone.

The Carboniferous limestone series is exposed as a rule wherever the overlying sandstone has been denuded away or cut through by erosion. It is well seen in the neighbourhood of Gebel Nukhul, of which mountain it forms most of the upper part. From Gebel Nukhul it extends as a broken plateau south-eastwards to near Wadi Baba, and then north-eastwards to Gebel Hazbar. It caps the high plateaux between Wadis Nasib and Lahian, and extends northwards to the Wadi Budaʿ, near which it disappears under the sandstone. To the south and east of Wadi Baba the limestone is well exposed on most of the higher hills, in some of them forming a plateau cap and in others being exposed in the hill faces and the bounding scarps of the wadis. A reference to the map on Plate I will give a better idea of the distribution of the limestone than any written

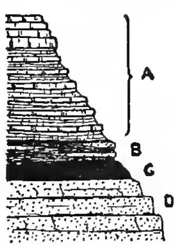

FIG. 27.—Section of Carboniferous limestone series, Um Bogma Mines. A, Limestone series; B, sandstones and sandy clays; C, ore-bed; D, Lower Carboniferous sandstone in thick beds.

description, for owing to the highly dissected nature of the country in which it occurs, the outlines of the exposures are extremely complicated. That so large an area of limestone is exposed in spite of the thinness of the series (its maximum thickness is only about forty metres and the average is much less than this), is chiefly due to the great hardness and resistance to weathering of some of the beds, which renders them good plateau-formers.

A section of the Carboniferous limestone series exposed on the east side of Gebel Nukhul, where the beds are best developed, is shown in Figure 26. The sequence from above downwards here is as follows :—

	Metres.
1. Thin beds of greyish crystalline dolomite, with some earthy limestone beds and abundant crinoid stems and *Syringopora*	4
2. Pink crystalline dolomite	5
3. Alternations of thin beds of crystalline dolomite and ochreous earthy limestones with abundance of brachiopods and *Zaphrentis*	17
4. Pink crystalline dolomite in thick beds	15
Total	41

To the south-east of Gebel Nukhul the limestone series becomes gradually thinner, and the lowest crystalline beds have in many places disappeared by solution, leaving thin bands of sandy clays, representing the insoluble residue of the dolomite, in their place, often with segregated iron and manganese ores at the base. A typical section measured near the Um Bogma mines (*see* Fig. 27) is :—

	Metres.
1. Pink and brown crystalline dolomite with encrinites and occasional silicified brachiopod casts...	5
2. Thin beds of crystalline dolomite, separated by ochreous earthy limestone and sandy beds	10
3. Red ochreous sandstones and sandy clays	2
4. Ore-bed (iron and manganese oxides)...	3
Total	19

Still further south-east, in Gebels Um Riglein and Sarabit el Khâdim, the limestone series is thinned out almost to vanishing, but even where the limestone is entirely absent, its horizon is marked by a thin band of iron and manganese ores separating the upper sandstones from the lower.

This thinning out of the limestones to the south-east doubtless corresponds to a gradual shallowing of the Carboniferous sea in that direction, but is also in part due to removal of limestone by solution in late Tertiary times.*

The appearance of the Carboniferous limestone in the field is quite unlike that of the Cretaceous and Eocene limestones further north; nor does it bear much resemblance to the mountain limestone of the British Carboniferous, with which its contained fossils show it to be at least homotaxial, if not indeed contemporaneous. The hard crystalline dolomite beds which form the major portion of the series show a rough weathered surface of a greyish brown tint, and are not always readily distinguishable by their colour from the overlying and underlying sandstones; the greater hardness of the dolomite, however, causes the edges of the beds to present much steeper faces than is usual in the sandstones, and the limestone horizon is thus commonly marked by a nearly vertical step in the scarps. The frequent presence of iron and manganese ores at the base of the series is another very useful guide in tracing the limits of the series, the dark ore-band being often very conspicuous from considerable distances. On fracture, the crystalline dolomite is usually of a pinkish colour, and until tested by the knife or acid bottle it might often be easily mistaken in the hand specimen for a fine-grained granite rich in orthoclase. Where the dolomite forms plateau surfaces, it is much broken up by changes of temperature, forming extremely rough ground to tramp over; the separated blocks and flakes preserve their hardness, being merely covered by a thin dark film on weathered surfaces. The mean of six analyses in the Government Analytical Laboratory of specimens of the crystalline limestones from different exposures gives the composition as:—

	Per cent.
SiO_2 and insoluble silicates	3·24
Fe_2O_3	1·94
CaO	30·38
MgO	19·80
MnO	0·24
CO_2	44·32
	99·92

* *See* p. 202.

from which it is evident that the rocks are strongly dolomitic in character, approaching in fact in composition to true dolomite, and that they owe their pink colouration to the presence of small amounts of iron and manganese carbonates.

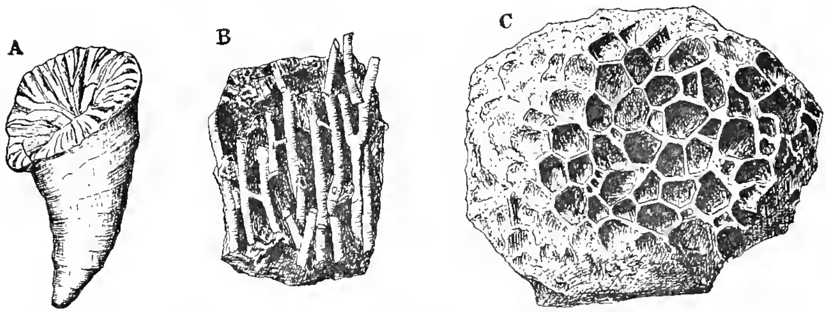

Fig. 28.—Carboniferous Corals. A, *Zaphrentis*; B, *Syringopora ramulosa* Goldfuss; C, *Favosites Michelini* Edw. et Haime, from the limestones of Gebel Nukhul. All the figures are slightly less than the natural size.

The beds which occupy the central position in the series are typically of a yellowish aspect, consisting of alternations of crystalline dolomite with ochreous earthy limestone beds. It is in these softer earthy layers that organic remains are most abundant and best preserved.

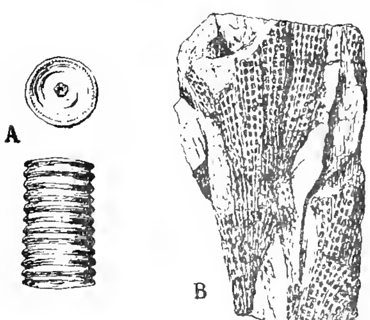

Fig. 29.—A, Stem-ossicles of a Crinoid (*Rhodocrinus*); B, *Fenestella*. From the Carboniferous limestone of Gebel Nukhul. Slightly less than natural size.

Fossils are on the whole rather scarce in the Carboniferous limestone series, but they are fairly frequently met with in certain localities, especially round the eastern flanks of Gebel Nukhul and in the upper part of Wadi Khaboba. The fossils are all marine, and mostly indicative of fairly deep water conditions.

Of corals, the simple form *Zaphrentis* (*see* Fig. 28) is by far the most frequent, hundreds of specimens having been collected from the earthy middle beds. The tabular *Syringopora* occurs more sparingly, mostly in the upper beds, while *Favosites* is still rarer.

Crinoid stems (*see* Fig. 29) are in some places extremely abundant, being often well seen on weathered surfaces of the hard upper beds.

Bryozoa are not infrequently met with in the earthy layers, the commonest forms being *Fenestella* and *Monticullipora.*

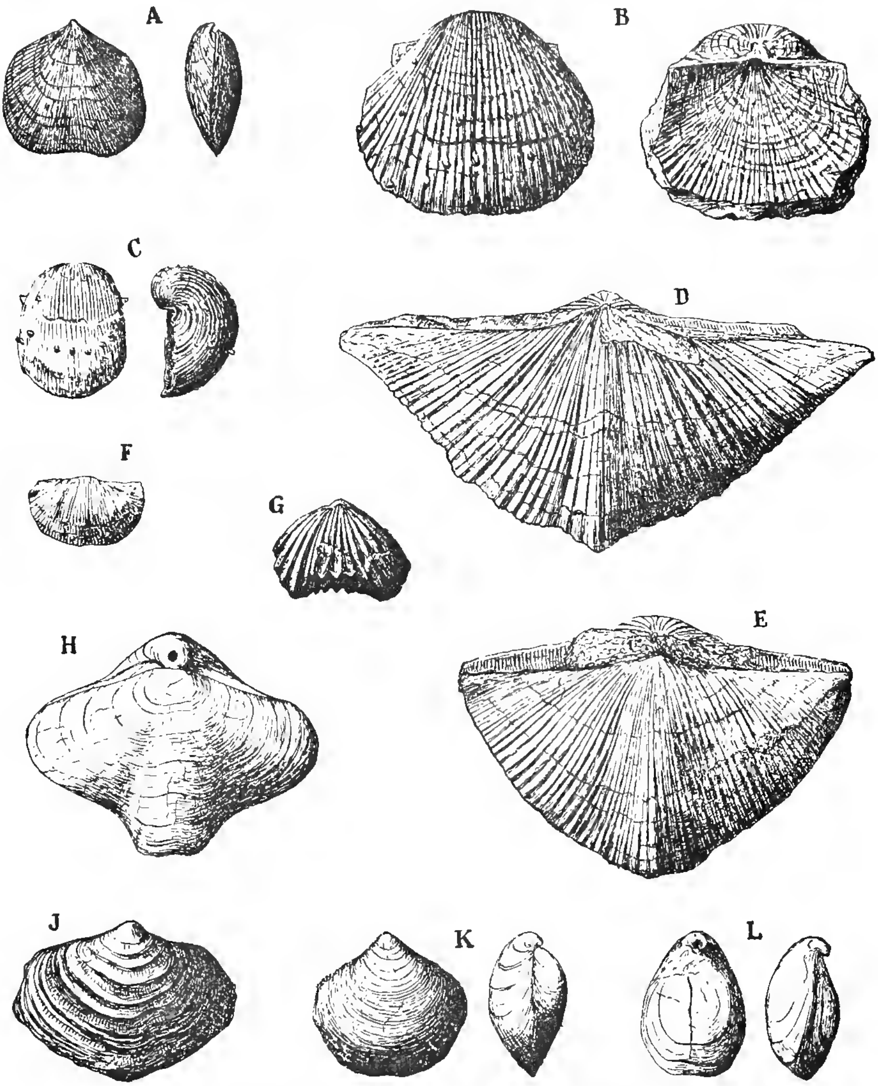

Fig. 30.—Carboniferous Brachiopods. A, *Orthis Michelini* L'Eveillé; B, *Productus semireticulatus* Martin; C, *Productus longispinus* Sowerby; D, *Spirifer* cf. *moosokhailensis* Dav.; E, *Spirifer striatus* Martin; F, *Chonetes hardrensis* Phillips; G, *Rhynchonella pleurodon* Phillips; H, *Athyris Roysii* L'Eveillé; J, *Athyris lamellosa* L'Eveillé; K, *Athyris planosulcata* Phillips; L, *Dielasma hastata* Sowerby. From the limestones of Gebel Nukhul. All the figures are slightly less than natural size.

Here as in other parts of the world it is the brachiopod fauna which is the most characteristic feature of the organic remains of the Carboniferous. By far the most common form is *Spirifer striatus* (Fig. 30). The more elongated and strongly ribbed *Spirifer* cf. *moosakhailensis* is

much less frequent, but is very characteristic. The small delicately sculptured *Orthis Michelini* is fairly abundant, and has been found not only in the middle earthy beds, but also sparingly in a silicified condition in the upper crystalline dolomite. Of the *Productidæ*, the most frequent form is the small *P. longispinus* ; *P. semireticulatus* and *P. scabriculus* are not very rare, though mostly found in a fragmentary condition. Of the genus *Athyris*, the species *A. lamellosa*, *A. Roysii*, and *A. planosulcata*, are all fairly frequent. Of Brachiopods more rarely met with, *Orthotetes* (*Streptorhynchus*) *crenistria*, *Syringothyris cuspidata*, *Chonetes hardrensis*, *Rhynchonella pleurodon*, and *Dielasma* (*Terebratula*) *hastata*, are the most striking forms ; the last two are quite rare.

Lamellibranchiata are poorly represented. The only form which is at all common is a new species of *Hinnites* (Fig. 31). This

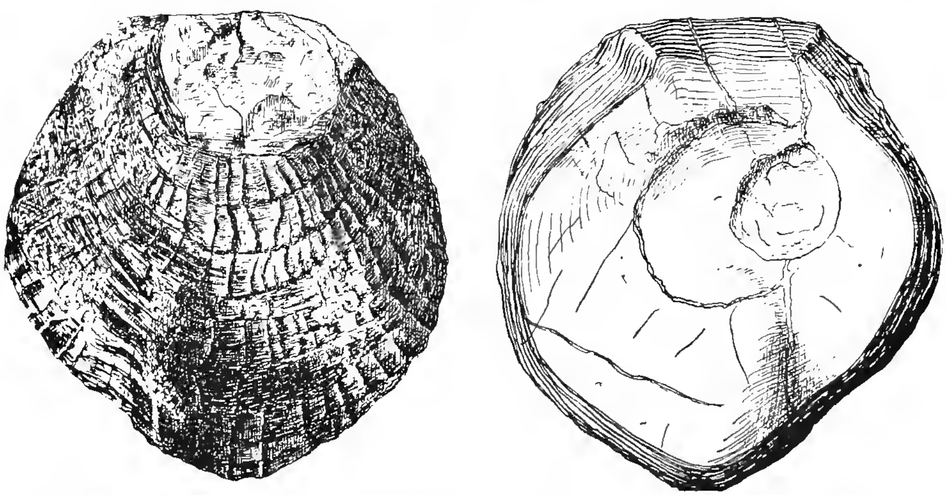

FIG. 31.—*Hinnites* sp. nov., a Carboniferous lamellibranch from the limestone of Gebel Nukhul; two-thirds of the natural size.

oyster-like fossil is fairly abundant in the earthy middle beds of the series, and is easily seen when present owing to its black colour ; but the shells are so friable and flaky that long search is usually necessary to get entire specimens. Of the genus *Edmondia*, only one or two casts were picked up, and these in situations where their exact horizon was not very certain ; the casts were of sandstone, and possibly came from the lowest beds of the Upper Carboniferous sandstone rather than from the limestone series.

Gasteropods are extremely scarce. A specimen of the characteristic *Bellerophon tenuifascia* (Fig. 32) and one or two other forms resembling *Murchisonia* and *Euomphalus* were picked up at Gebel Nukhul.

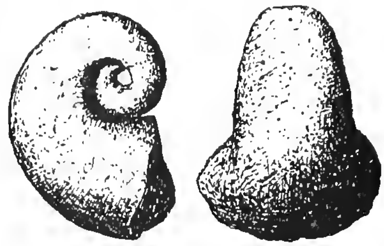

FIG. 32.—*Bellerophon tenuifascia*. A, Carboniferous gasteropod, from Gebel Nukhul. Slightly less than the natural size.

The vertebrates are represented only by the palatal teeth of selachian fishes, which are occasionally met with in the hard crystalline dolomites. They are conspicuous in the rocks by their very high polish and sometimes opalescent appearance; with a lens, the surfaces are seen to be minutely pitted. The specimens collected have been referred by Mr. Bullen Newton to *Psephodus* and *Psammodus*.

For reasons which will be given in Chapter VII (page 200), the deposits of iron and manganese ores which occur in many places at the base of the Carboniferous limestones are believed not to be of Carboniferous age, but to have been formed in late Tertiary times, and to owe their origin to solution of the dolomitic limestones by thermal waters coming up fault fissures, and concentration and oxidation of iron and manganese carbonates near the faults.

It is of interest to compare the Carboniferous limestones of Sinai with those of Wadi Araba in Egypt, on the western side of the Gulf of Suez. There can be no doubt that the limestone series was originally continuous right across the gulf. Unfortunately the Wadi Araba occurrence has not been mapped or investigated with anything like the same detail as that of Sinai, so that a thorough comparison is hardly possible. But from the reconnaissances made by Walther in 1887, and by myself in 1909, it appears that there was a thinning-out of the limestone to the west. The total thickness of the limestone series in Wadi Araba is less than half that developed in Sinai, and the beds are of a more marly nature, with only thin bands of hard limestone; there is no evidence that the Carboniferous sea extended as far west as the Nile Valley. The fossils on both sides of the gulf present a general similarity, such forms as *Zaphrentis*, *Orthotetes crenistria*, *Productus semireticulatus*, *Spirifer* cf. *moosakhailensis*, *Rhynchonella pleurodon*, and *Dielasma hastata*, being common to the two areas; but the brachiopod *Athyris ambigua* and the lamellibranch *Myalina*

depressa, both occurring in abundance in the Wadi Araba, have not been found in Sinai.*

List of Carboniferous Fossils.

Collected by the Author from the Limestone of Sinai.

Corals :—

Zaphrentis sp., Wadi Budra, Um Bogma, Gebel Nukhul, Wadi Khaboba.
Favosites Michelini Edw. et Haime, Gebel Nukhul.
Syringopora ramulosa Goldfuss, Gebel Hazbar, Um Bogma, Gebel Nukhul.

Crinoids :—

Stem-ossicles, various.

Bryozoa :—

Coscinium sp., Wadi Khaboba, Gebel Nukhul.
Fenestella sp., Gebel Nukhul.
Monticulipora sp., Um Bogma, Gebel Nukhul.
Heterotrypa ramosa Edw. et Haime, Gebel Nukhul.

Brachiopoda (provisional determinations by Mr. Bullen Newton) :—

Rhynchonella pleurodon Phillips, Wadi Nasib, Gebel Nukhul.
Athyris planosulcata Phillips, Gebel Nukhul.
Athyris Roysii L'Eveillé, Gebel Nukhul.
Athyris lamellosa L'Eveillé, Gebel Nukhul.
Productus longispinus Sowerby, Wadi Khaboba, Gebel Nukhul.
Productus scabriculus Martin, Wadi Khaboba, Gebel Nukhul.
Productus semireticulatus Martin, Gebel Nukhul.
Spirifer cf. *moosakhailensis*, Gebel Nukhul, Wadi Khaboba.

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* Barron's statement ("Western Sinai," p. 168) that the Carboniferous limestones of Wadi Araba are three times as thick as those in Sinai is an error, doubtless due to his having been misled by Prof. Walther's section (*Zeitsch. d. Deutsch. Geolog. Gesellschaft*, 1890, p. 427). In this section Prof. Walther has shaded the entire Carboniferous, consisting mostly of sandstones, as *Kohlenkalk*, though he gives a correct description of the beds in his paper. Schweinfurth (*Bull. Inst. Egyptien*, 1887, p. 161) has also classed the sandstones as *Terrains du Calcaire Carbonifère*, a totally misleading description.

Spirifer cf. *striatus* Martin, Gebel Nukhul, Um Bogma, Wadi Khaboba.
Spirifer integricostatus Phillips, Gebel Nukhul.
Spiriferina laminosa M'Coy, Gebel Nukhul.
Orthotetes crenistria Phillips, Gebel Nukhul.
Dielasma hastata Sowerby, Gebel Nukhul, Wadi Khaboba.
Syringothyris cuspidata Martin, Gebel Nukhul.
Chonetes hardrensis Phillips, Gebel Nukhul, Wadi Khaboba.
Orthis Michelini L'Eveillé, Gebel Nukhul, Wadi Khaboba.

LAMELLIBRANCHIATA :—

Edmondia sp., Gebel Musaba' Salâma, Gebel Nukhul.
Hinnites sp. nov., Gebel Nukhul, Wadi Khaboba.

GASTROPODA :—

Bellerophon tenuifascia, Um Bogma.

PISCES :—

Psephodus sp., Wadi Bud'a.
Psammodus sp., Um Bogma.

The Lower Carboniferous Sandstone.

The Lower Carboniferous sandstone series, which underlies conformably the Carboniferous limestone and rests everywhere on a foundation of igneous and metamorphic rocks, is exposed wherever the base of the limestone is seen, and in addition is found capping numerous mountain tracts from which the overlying limestone has been denuded away. Its upper and lower limits being marked by abrupt lithological changes, the boundaries of the lower Carboniferous sandstone are easily traced in the field; the extent and distribution of the series will be more readily grasped from the map (Plate I) than from any description.

In all the exposures where the entire series has been seen, its thickness appears to be remarkably constant, being about 130 metres, and it appears to have been laid down on a nearly level floor, formed by the planed-down surface of the underlying igneous and metamorphic complex.

The series consists mainly of sandstones, but there are considerable intercalations of shaly beds. A typical section, measured between the mouths of Wadis Um Rinna and Malha, is shown in Figure 33. The sequence downwards is here :—

	Metres.
1. Reddish and brownish sandstone	70
2. Greenish shaly beds	30
3. Red sandstone and grit...	30
Total	130

Besides containing a relatively larger proportion of shaly beds, the Lower Carboniferous sandstones are typically tougher and more compact than the Upper Carboniferous and Nubian sandstones, owing to their containing more kaolinic cementing matter. It is not difficult to account for this circumstance by considering that these basal sandstones have no doubt been derived from the wearing down of the underlying igneous rocks, the felspars of which have furnished the kaolinic matter by their decomposition. Another interesting feature, which points to the same source, is that the red colouration of the sandstone is always most pronounced where the underlying igneous rocks are dioritic in character, while where the underlying rocks are granitic the sandstones are paler in colour and even nearly white; so marked are these colour changes, that it is possible by tracing them to map the boundary between the granites and diorites with very fair approximation. That the lowest beds should typically be rather coarse grits is also natural if the sands were derived from the disintegration of the crystalline rocks below; we can picture the ancient peneplain, covered with the products of its surface weathering, sinking gradually beneath the Carboniferous sea, the sedimentary beds first formed on the sea bottom being composed of detrital material redistributed almost on the spot where it originated.

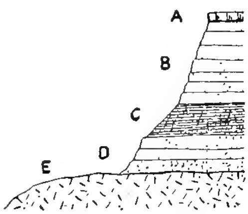

FIG. 33.—Section of the Lower Carboniferous sandstone, near mouth of Wadi Um Rinna. A, thin limestone cap; B, reddish and brownish sandstone; C, greenish shaly beds; D, red sandstone and grit; E, diorite.

Organic remains are scarce in the Lower Carboniferous sandstone, being confined to markings, some of which can be identified as worm-tracks and medusæ, while others are of obscure origin. Probably

all are marine. One of the most characteristic types of marking in these rocks (*see* the second illustration in Fig. 34) resembles masses of double wheat grains; I have not been able to find out what these are.

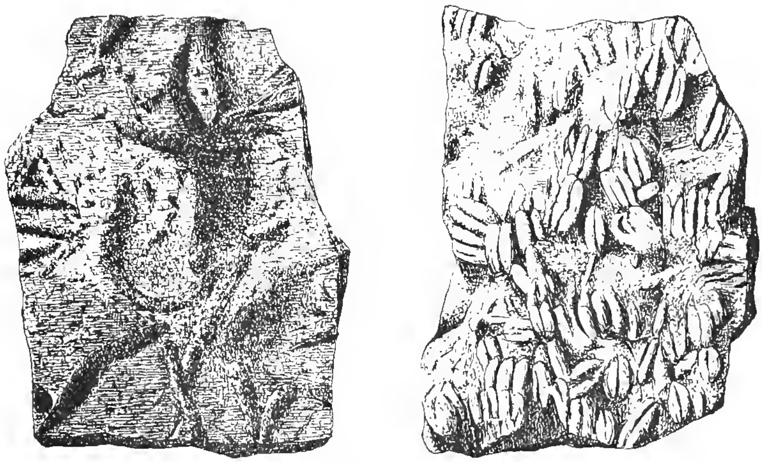

FIG. 34.—Markings in the Lower Carboniferous sandstone, near Um Bogma.

It is at an horizon near the top of the Lower Carboniferous sandstone that turquoises occur at Sarabit el Khâdim and elsewhere. As already remarked on page 11, the deposits at this place have been almost entirely worked out, and I could not find enough data for a sure conclusion as to the origin of the gems; but it is almost certain that both the turquoises and the films of copper carbonate which are occasionally seen in the rocks are deposits from percolating waters, and they were probably formed in the same late Tertiary times as the manganese and iron ores which occur at the base of the limestone.

PRE-CARBONIFEROUS ROCKS.

The lowest Carboniferous rocks in this part of Sinai rest everywhere on the planed-down surface of a mighty complex of igneous and metamorphic rocks, of which the principal members are granite, diorite, and micaceous gneisses, with intrusions of porphyry. The different igneous rocks, though sometimes sharply marked off into types, often pass into each other by insensible gradations, and as the

metamorphism has affected different parts unequally, there is a similar gradual passage from igneous to schistose forms. To have attempted to unravel the complexities of this igneo-metamorphic mass, and to separate the different lithological types, would have occupied more time than all the rest of the mapping, and it is doubtful if the resulting additions to knowledge from such a small area would have been worth the expense, even had time and funds been available. The whole great mass of Pre-Carboniferous rocks was therefore mapped as a single unit. I may, however, here set down a few notes on the characters observed at certain points, on the principle that fragmentary observations are better than none at all.

Wadi Khaboba. Grey gneiss with red orthoclase, resembling the well known rock of the Saxon Erzgebirge, with dykes of quartz felsite and dark doleritic rock.

Wadi el Sih. Medium grained diorite with dykes of dark felsite and very hard purple porphyry.

Wadi Nukhul. Grey gneiss.

Base of Gebel Um Riglein. Grey and red granite.

Wadi Sahu. Pink acid granite.

Gebel Samrâ. Grey granite and gneiss with hornblende and biotite.

West of Wadi Tila'gebir. Coarse grained pink granite resembling the Aswân rock, with great development of epidote near faults, making the hills look quite green in places.

Wadi Siheiya and East of it. Well foliated dark gneisses and schists rich in biotite.

South-east Corner of Map on Plate I. Biotite gneiss.

Round Gebel Moneiga. Felspathic gneiss.

As to the age of these Pre-Carboniferous rocks, the only observation I could make was that since they had been contorted and invaded by dykes and then planed down prior to the deposition on

them of the lowest Carboniferous strata, they were obviously considerably older than the Carboniferous, and from the general high degree of metamorphism I should have been inclined to assign to them an Archæan age. But Barron* records that further south he has found ancient sediments involved in the complex, and hence regards them as early Palæozoic. It may be the good fortune of some future geologist to find organic remains of the earlier Palæozoic period in the old sediments discovered by Barron, and thus to obtain fossil evidence carrying the history of Sinai backwards beyond the Lower Carboniferous, which at present is the limit of our ascertained geological chronology both in Sinai and in Egypt.

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* "Western Sinai," p. 203.

CHAPTER VII.

PHYSICAL GEOLOGY.

The physical geology of West-Central Sinai may conveniently be discussed under the following four heads :—

1. Desert Denudation.
2. Tectonic Disturbances.
3. Ore Deposits.
4. Hydrocarbons and Oil.

DESERT DENUDATION.

The denuding agencies at work in the present day in Sinai may be classified as follows :—

(*A*) *Major Agencies* :—

1. Disintegration of rocks by the diurnal variation of temperature.
2. Transport of disintegrated material and erosion by rainfall and consequent running water.
3. Transport of disintegrated material and erosion by wind.

(*B*) *Minor Agencies* :—

4. Chemical decomposition of rocks.
5. Disintegration by frost.
6. Solution and removal of rock by the action of meteoric waters.
7. Disintegration by crystallizing salts.

As opposing agencies resisting denudation, we have :—

1. Action of dew and very light rain in indurating rock surfaces.
2. Action of plants in resisting the movement of sand.
3. Deposition of carbonates and silicates from evaporating water.

It need hardly be said that the forces opposed to denudation are immensely less powerful than their adversaries; some of them are, however, of importance as accounting for certain curious forms of weathering which result from their interaction with denuding agencies.

Desintegration of Rocks by Diurnal Variation of Temperature.

Owing to the absence of any blanket of soil or vegetation, the temperature-range of the desert surface is extremely high as compared with that of the land surface in soil-clothed countries. The diurnal range of the shade temperature in the air in Sinai in summer may be as much as 20° C., but owing to the bareness of the rocks this is far from representing the range of temperature of the rocks themselves. Absorbing the solar radiation by day, and parting with their heat by radiation under clear skies by night, the superficial rock layers experience a range at least double that of the air in the shade. The magnitude of the movements set up by the alternate expansion and contraction due to the diurnal temperature range varies with the coefficient of expansion of the rock materials. The resulting stresses depend on the degree of consolidation of the rock; for if the rock is porous, the expansion can be accommodated by a reduction in the size of the pores, and *vice versa*; while if the rock is compact, the variations in size of its grains must result in internal stresses, and if these stresses transcend the resistance of the rock, disintegration or fracture must result. The action is complicated in crystalline rocks by the fact that many crystals have different coefficients of expansion, and different ultimate resistances, in different directions, as well as by the weakness to shearing of crystals along their planes of cleavage. Thus a porous sandstone may still cohere sufficiently to remain a rock, though its particles be loosened by alternate expansion and contraction, while a felspathic granite, though a much harder rock, may break up under the same temperature-range, because on the one hand its particles have no room to expand, and on the other its felspars shear readily along their cleavage planes. Homogeneous compact rocks yield to stress by sudden fracture, while heterogeneous rocks crumble to fragments, as we see by comparing the flaky yielding of flints with the powdery disintegration of granites.

The conditions of exposure are another great factor affecting disintegration. Many years ago I noticed that the south-facing walls of temples on the Island of Philæ were far more damaged by disintegration than those facing north, and the obvious explanation was that in north latitudes surfaces facing to the south were more exposed to solar radiation than those facing in other directions. In Sinai a similar dependance of disintegration on exposure is observable on many mountains. The relatively rapid disintegration of the face of Gebel el Tih is an example, and another is to be found in Gebel Moneiga, where the south faces of the basal granite are so disintegrated that it is difficult to walk on quite moderate slopes, owing to the rounded quartz grains rolling about under one's boots almost like steel balls from the bearings of a bicycle.

This disintegration by temperature-change can of course only go on to a moderate depth, unless its products are continually taken away by some transporting agency. Unless removed by wind or water, the disintegrated matter soon forms a blanket effectually protecting the lower layers of rock from further action. But the effect of temperature-change is not finished when it has broken up the rock, for we have to bear in mind that the resulting sand provides the tools by which wind and water perform further erosion. Every sand grain set loose by temperature-change probably acts as a milling cutter later on in its career to remove several times its own bulk from a softer rock. Temperature-variation is in fact probably the most potent of all denuding agencies acting in the desert, for the other eroding agents would be powerless but for its provision of cutting tools, and transporting agents would have little to transport but for its direct and indirect products.

Transport of Disintegrated Material and Erosion by Rainfall and Consequent Running Water.

Though Sinai has a very arid climate, some rain falls there in every year. The commonest type of rainfall is a mere drizzle or very gentle shower, usually lasting only a few minutes, or at most an hour or so. Rain of this type, though it accomplishes some redistribution of disintegrated material when of sufficient duration, acts rather as a conserver than as a destructive agent on the rocks. The amount of the

fall being only sufficient to wet the surfaces, run-off is negligible, and when the shower is over the film of water soon disappears, being partly absorbed into the rocks and partly evaporated into the air; during the time it lingers on the surface, however, the watery film dissolves minute amounts of carbonates and silicates from the rock, and on evaporation this dissolved stony matter is redeposited in the superficial pores, thus forming a skin of more compact and resistant nature than the interior of the mass.

It is only on the rarer occasions of heavier rainstorms, such as may happen on an average once in three or four years, that meteoric waters become at all powerful as an agent of denudation. At such times, though the total fall may only be half an inch or so, the rain descends at a vastly more rapid rate than that at which the stony ground can absorb it, and the run-off almost equals the rainfall. All the coarse sand and debris resulting from disintegration of the rocks by temperature-changes—material which has been accumulating, it may be, for years—is swept away into the main trunk wadis by myriads of resulting small streams, leaving the rock surfaces bare again for further disintegration to go on. The usually dry wadis at such times become the scene of raging torrents, sweeping along the accumulated debris and eroding their channels.

Heavy rainstorms are so rare in Sinai that it seldom falls to the traveller's lot to observe their action actually going on, though the effects remain permanently visible in the scouring out of the wadis and the undercutting of the rocky walls. When camped in the Wadi Abu Qâda on February 14, 1913, I had the good fortune to witness one of these "seils," as the short-lived streams are called, pass by my camp. Two photographs of this "seil" are shown on Plate XX; the upper view shows the front of the on-coming stream, while in the lower one the Arabs are seen manifesting their joy by dancing about in the sweet though muddy water. This particular "seil" was by no means a large or powerful one. There had been only a moderate rainfall in the hills to the east the day before, and the "seil" was rather unexpected, though I had taken the precaution to pitch my tents on a gravel bank slightly above the main bed of the wadi. The water appeared about 11 o'clock in the forenoon, coming down the wadi at a pace of about eight kilometres an hour in a stream about four metres wide and fifteen centimetres deep; it continued to pass till

about one o'clock in the afternoon, then ceased, leaving pools and scum in the wadi bed.

The larger "seils," which occur on an average only once in ten years or so, are immensely more powerful as eroding agents than the one just described. From the appearance of the side walls of such wadis as Baba and Shellal, the streams at times must be several metres in depth, and the slopes of the wadi-floors are so rapid that the torrents must rush along with velocities sufficient to move blocks of rock weighing tons, and to plane out their rocky channels by the grinding action of their load of debris.

Besides the erosion of the trunk channels by the main streams, an enormous amount of rock is removed by the lateral drainages, and the erosion effects where these join the main drainage lines are often very striking. A characteristic feature of Sinai hydrography, especially in the limestone districts, is the prominence of "hanging valleys." Lateral drainages frequently reach the main wadi by falling over a precipice, in some cases a hundred metres or more in height, and there is sometimes a great vertical semi-cylindrical groove cut by the falling water in the side wall of the wadi. This type of erosion is best seen where the drop takes place over the edge of a hard bed overlying a great thickness of chalky rocks, as in Wadi Nukhul (*see* Fig. 35). The semi-cylindrical shape of the vertical groove is doubtless due to rotation set up where the waters meet. That the main channel should be deepening itself at a much more rapid rate than its lateral feeders is of course easily accounted for by the vastly greater volume of water and debris which it carries.

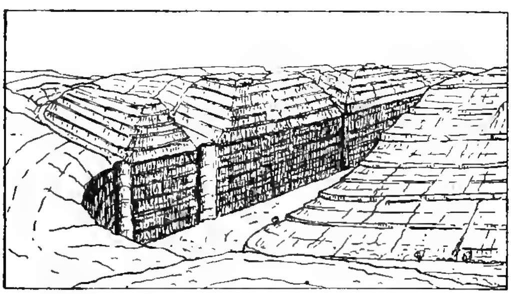

FIG. 35.—Diagrammatic sketch of "hanging valleys" forming lateral feeders to Wadi Nukhul.

Whether the "seils" in a wadi will carry their debris into the sea or not depends mainly on the degree of slope of the tail-reaches of the wadi, and this in turn is determined by the degree of maturity reached by the denudation. Where high hills extend right to the coast, as at Gebel Hammam Faraûn, the tail-reaches of the wadis

Two views of the "Seil" in Wadi Abu Qâda, February 14, 1913.

commonly preserve a rapid slope, and the larger "seils" convey their material into the sea. But where, as in the case of Wadi Baba, the drainage, after leaving the hills, has to pass over a sloping plain to reach the sea, it spreads out like a fan, with rapidly lessening velocity, and consequently the transported material is dropped on the plain. In the present day the highest points of the various coast-plains of Sinai and Egypt are always found to be at the mouths of great wadis. In the case of the Plain of El Markhâ, for instance (*see* Plate I), the level at the mouth of Wadi Baba is 105 metres above sea, falling to sixty-nine metres at El Mereighat to the north, and to seventy-five metres at the foot of the hills a kilometre to the south. The part of the plain of El Markhâ which is called 'Elwa Baba has in fact the shape of the half of a very flat cone, whose vertical axis is at the mouth of Wadi Baba. Once this dropping of material in the form of a fan on the coast plain has begun, it is bound to be progressive unless a change of climate sets in, for the gradual raising of the level of the wadi mouth by dropped material causes a flattening of the slope of the lower reaches of the wadi, and tends still further to lessen the velocity of efflux and to increase the rate of deposition.

If instead of considering a great wadi like Baba, which has reached such a mature stage that deposition balances erosion in its lower reaches, we examine the shorter Wadi Dafari, which throughout its course has a rapid slope and is still in the highly erosive stage, we see a remarkable difference in its terminal career. Though Dafari, like Baba, reaches the sea over the plain of El Markhâ, its drainage rushes out from the mountains on to the plain with such a velocity as to *cut through* the gravel deposited from its greater neighbour, and for a kilometre or so it flows in a cut between high gravel banks; but the plain is so wide that even here the impetus is not sufficiently strong to counteract for more than a moderate distance the lowering of the velocity by spreading of the issuing stream, and the Wadi Dafari conveys little or none of its debris to the actual coast.

When we reflect upon the rarity at the present day of those considerable rain-storms which alone are capable of even for a short time covering the beds of the trunk wadis with water, and the immense depths (three or four hundred metres) to which these wadis have been eroded through the hardest rocks, we cannot fail to realize that an enormous period of time must have been required to excavate the

channels under anything like the present conditions of rainfall. Though exact calculations are impossible for lack of data, we may make an attempt to estimate very roughly what that duration must have been. It has been ascertained that the Nile, sweeping yearly some 100,000 million tons of water, laden with sixty million tons of silt, over the gneiss barrier of Semna in Nubia, can lower its rocky bed by some two millimetres per year.* The "seils" in the great wadis of Sinai convey, of course, much more efficient grinding material than Nile silt, but they only exert their powers on an average for about one day in ten years. Let us suppose that, at a liberal estimate, the erosive power of a "seil" in Wadi Baba is equal to that of a whole year's Nile flow at Semna; this gives us a lowering of the bed of Baba of two millimetres in ten years, and to excavate the channel to its present depth of 400 metres at this rate will have occupied two million years. The erosion of the wadis has doubtless all taken place since Pliocene times, and consequently, if the above rough estimate is accepted as anywhere near the probable truth, we have either got to regard two million years as the approximate duration of geological time since the Pliocene period, or to postulate a former greater rainfall than the present one. The latter hypothesis seems the more likely, and is to some extent supported by other observations, such as the finding of oak leaves in the calcareous tufa of the Oases. The deeply cut wadis of Egypt and Sinai form in fact one of the strongest arguments in favour of a moister climate in the Pleistocene period. At the same time it is not necessary to suppose that the climatic changes have been very great, for recent investigations into the effect of radio-active matter in the terrestrial crust have greatly changed our ideas as to the physical limits to the duration of geological time, and there are certain facts, such as for instance the uniformity of the semi-cylindrical grooves shown in Figure 35, which tend to show that the conditions of erosion have for long ages remained nearly constant.

Transport of Disintegrated Material and Erosion by Wind.

Even the strongest winds can only move small pebbles, and an average strong wind can only carry sand. The power of wind as a transporting agent is thus more restricted than that of water, in that

* Ball, "The Semna Cataract." Q.J.G.S., Vol. 59 (1903), p. 74.

it can operate only on the finer particles of disintegrated rock material; but this restriction is probably more than compensated by the circumstance that for one heavy rain-storm there are scores of wind-storms, and hundreds of more or less windy days. Another important thing to remember in comparing the actions of wind and water is that water action is only prominently manifested along grooves, while wind action takes place on the much more extensive open surface, where its effects, though they may be very considerable, are less striking because they result in a general lowering; resistant features will outstand for a time, but the more they outstand the more they are exposed to demolition by undercutting, and we can expect no such permanent witness to the total amount of erosion by wind as those which testify to the magnitude of water action. The most striking evidence of the transporting agency of the wind is that furnished by the great accumulations of wind-borne sand in the Debbet el Qeri and elsewhere; but it is important to note that even these accumulations form only a small proportion of the total transported material, for much blown sand and dust will have found a temporary lodgment among the superficial debris on the otherwise bare desert, and will have been removed by water action along with the products of local disintegration.

Though it is with hot southerly winds that one usually associates the idea of sandstorms, owing to the fact that with such winds the air is commonly darkened by sand and dust, yet I believe it is by the cooler northerly winds that the major portion of wind erosion and transport is effected. So far as my experience goes, the northern winds in this part of Sinai are on the average much stronger and more frequent than the south ones;* and there can be no doubt that the sand of Debet el Qeri is gradually progressing southwards, because it has overflowed into the heads of the southward draining wadis.

Besides redistributing the sand produced by the disintegration of the rocks, the sand-laden wind acts as a powerful instrument of erosion. Its effects are best seen where the rocks show variations in hardness, either consisting of alternate hard and soft beds or representing local differences in resisting power owing to other causes. Where

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* Capt Wilson's experience was the same in 1868–1869 He states ("Ordnance Survey of Sinai," p. 240) that the prevailing winds were from the north and west.

the rock is nearly homogeneous, it is merely ground away and nothing remains to tell the tale, but where harder portions stand out, these give us a clue to the amount of softer material which has been removed. There are in this part of Sinai no such vast expanses of wind-swept and polished stony surfaces as are found in the Libyan desert, for the country is so rugged that near the ground the wind is broken up into eddies; but these same eddies do much to grind out hollows in the rocks, often producing the most fantastic forms, such as are shown on Plate XXI.

Chemical Decomposition of Rocks.

Though chemical changes are far less powerful than physical processes in the disintegration of rocks in Sinai, they nevertheless play a part which is not quite negligible. The effects of chemical changes are most evident in the igneous rocks, such as granites, which contain felspars. Under the influence of weathering, the felspars in the exposed surfaces undergo decomposition, with the formation of kaolin, and the resistance of the rock to physical denuding agents is thereby much reduced.

The combined actions of chemical changes and expansion and contraction by temperature-changes serve to explain the remarkable exfoliation, or scaling off of shells, from granitic masses, the precise cause of which has long been a puzzle. It has of course always been believed, quite correctly, that the main agent in the formation of these shells is the expansion and contraction brought about by temperature changes. But a uniform rock will yield to shearing stress along the plane where the stress is a maximum—that is, in the case of shearing stresses produced by temperature changes, along the plane where the temperature gradient is a maximum. Now the temperature gradient in a uniform mass of rock heated or cooled externally has its greatest value *at the surface*, so that such a rock cannot yield to the stresses by the flaking off of a shell of finite thickness. The essential condition for the detachment of such a shell is that the external crust shall possess different resisting powers to the interior kernel. If the separated granitic shell be struck with a hammer, it is always found that no matter how hard and solid it looks, it falls easily to pieces, and on careful examination its felspars are found to be more or less

Weathered sandstone, Dirret el Nasib.

highly kaolinized. The thickness of the shell, which may be from less than a centimetre to ten centimetres or more, corresponds in fact to the depth to which decomposition of the felspars has gone on. Thus in Figure 36, which represents a diagrammatic section through an exposed block of granite, the outer crust A, in which the felspars have undergone partial kaolinization, is in a very different condition as regards resistance to stress from the interior portion B, where the felspars are still fresh; and the limit between the two is frequently very sharply marked. The rock yields most readily along the surface of separation C–C, much in the same way as a steel bar, subjected to alternations of stress, will yield at a point where its cross section changes suddenly, even though the point is not that of minimum cross section of the bar. The separation of the shell is probably quite sudden, occurring during a night of rapid radiation after a specially hot still day. That the exfoliated portion coheres into a shell, instead of breaking up into sand, is partly due to the kaolinic matter acting as a kind of cement, and partly to the induration of the external surface of the rock by repeated evaporation of films of dew and gentle rain; this latter action will be considered further on (page 177).

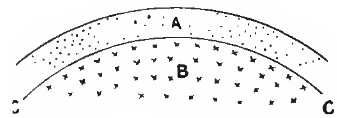


FIG. 36.—Diagrammatic section through a block of exfoliating granite. A, partially decomposed outer crust; B, fresh interior; C,C, surface of yielding.

Disintegration by Frost.

Though frost is occasionally experienced in Sinai, especially among the higher mountains, it exerts so little power as to be negligible in comparison with other agents of denudation. The pores of the rocks usually contain but little water, without which frost is powerless, and the duration of the frosts being seldom more than a few hours at a time, the freezing temperature never extends to more than a minute depth into the stone.

Solution and Removal of Rock by the Action of Meteoric Waters.

The powerful solvent action of rain water, containing as it does small amounts of carbonic acid in solution, on limestone and other rocks is well known, and there can be no doubt that a certain amount of denudation is accomplished by this means. But the rainfall in

Sinai is so scanty, that the total rock carried off in solution must be very small in comparison with that removed by other agencies. The effects of solution are most evident where the limestones contain gypsum, which is one of the most soluble of rock-forming minerals. Except when the rain is heavy enough to produce a perceptible run-off, the effects of solution on other than gypseous rocks tend rather to resist than to favour denudation, for the dissolved matter is re-deposited in the pores of the rock as the water evaporates, producing a hard resistant skin.

Disintegration by Crystallizing Salts.

Most of the chalky limestones, marls, and clays contain a small proportion of soluble salts, principally common salt and gypsum. The salts are dissolved by percolating waters, and when these evaporate at the exposed surfaces, the salts crystallize out. In the case of chalky rocks, the formation of the crystals takes place in and underneath the surface layers of the stone, and results in a physical disintegration of the rock; the action is exactly similar to that which has caused so much damage to buildings in Cairo.* Where the crystallization takes place from the surface of the ground composed of clays and marls, the usual effect is to raise small sharp hard ridges on the surface, like tiny solidified waves; these often form a protective crust preventing the mechanical removal of the softer underlying rock by wind, and thus tend rather to retard than to promote denudation. It is in these softer marls and clays that the largest proportion of salt occurs; the harder limestones contain so little salt, and are so seldom thoroughly wetted, that the amount of disintegration caused by crystallization is usually very small.

Action of Dew and Very Light Rain in Indurating Rock Surfaces.

Heavy dews are by no means infrequent in winter in the Sinai deserts, more especially in the mountainous regions. In fact the air is sometimes so moist in the early morning that plane table mapping cannot be commenced till a couple of hours or so after sunrise, owing

* *See* A. Lucas, "The Disintegration and Preservation of Building Stones in Egypt," Cairo, 1915.

to the saturation of the paper. And gentle drizzly rains, often lasting only a short time, occur usually several times in a year. The result of dew and light rains falling in the night is that a film of water remains on the exposed rock surfaces for several hours, during which time it dissolves small amounts of carbonates and silicates in the rocks, only to deposit its solid contents again on evaporation in the morning; and the deposited matter, being in a molecular condition, is left in the minutest pores of the rock, converting, for instance, the superficial layer of a soft sandstone into a hard skin more resembling quartzite. Where the desert surface is flat, the effect of dew is merely to indurate pretty uniformly the exposed surfaces of the stones; the top of Gebel el Tih is covered with limestone blocks having a hard brown skin formed in this way. In the case of scarps, where the alternations of hard and soft beds gives rise to projecting steps and ledges, the dew from the horizontal surfaces trickles over the edges and down the vertical face, producing a similar hardening wherever it lingers. But the distribution of the trickles down the vertical faces is highly irregular, being governed by minor irregularities in the edge, and consequently patches of the vertical faces are left unprotected by any indurated skin. Temperature changes and wind action now operate most rapidly on the softer unprotected portions, scooping out hollows in the rock face and giving rise to honeycombing; this is specially well seen in the Upper Carboniferous sandstones round Sarabit el Khâdim (*see* Plate XIV), where the natural rock often possesses only a very slight degree of coherence and is only capable of a high degree of resistance where the induration of its surface has taken place. Once the action of disintegration and wind erosion has undercut the hardened portions (*see* Fig. 37) the interior of the cavity is effectually protected from further wetting, while the indurated projecting portions are still exposed as dew catchers and tend to be rendered still further resistant. The manner in which an overhanging lip will prevent the access of moisture to the interior is well known to builders, who cut a groove or "throat" along the underside of coping stones to keep a wall dry; and to telegraph engineers, who adopt the shape of an

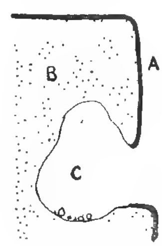


FIG. 37.—Diagram illustrating the process of honeycombing of rocks by wind action. A, indurated skin; B, soft interior; C, hollow excavated by wind and sand.

inverted cup for their insulators. In this way there are formed some very curious pendant forms; and it is to be noted that the point of the pendant, which is most exposed to attack by disintegrating faces, is at the same time the best protected, because water remains longer on its point than elsewhere, and the induration can in consequence here reach its maximum. Another thing worth pointing out is that the more such pendant and overhanging masses develop, the greater the local eddies produced by the wind, and the faster the grinding out of the cavities will go on. Sometimes fragments of hard rock or included pebbles drop into the cavities, and these serve as grinding tools for the wind to operate with.

At some places the honeycombing of the rock faces takes on a more or less regular pattern, like a grating (*see* the uppermost illustration on Plate XXII). The cause of this is to be found in the regularity of the planes of stratification and vertical jointing of the rock, and the tendency of water to linger in the cracks. The faces of the cracks are indurated, and the intervening rock is easily weathered out. When bivouacking under a scarp of this kind it is frequently handy to use the cavities as natural cupboards, to put one's possessions in to keep them safe from dew.

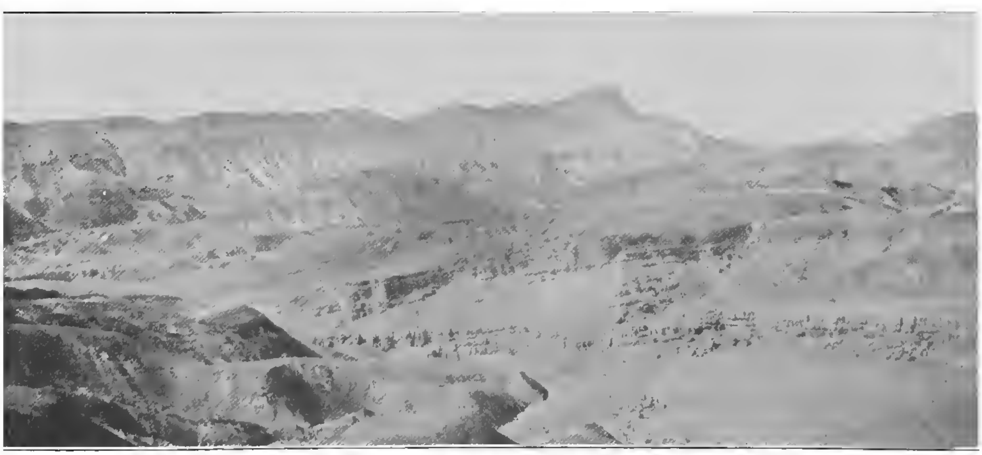
This explanation of the widespread superficial induration of rocks in deserts by the action of dew and gentle rains, though arrived at independently by myself, is, I find, not new, having been suggested by Linck in 1900.* It has been combated by Professor Walther,† on the mistaken idea that dew never falls in the desert proper, but only in the tracts bordering standing water; he regards the superficial induration of desert rocks as being caused by the evaporation of "quarry water" coming from *within* them. That so keen an observer as the author of the *Gesetz der Wüstenbildung* should have been led to so erroneous a conclusion as that dew never falls in the heart of the Egyptian and Sinai deserts illustrates the risk of generalizing from a limited experience. My long wanderings in Egypt and Sinai enable me to state that there is no portion of these deserts in which dew-falls do not occur in the winter months. The falls are naturally

* *Ueber die dunklen Rinden der Gesteine der Wüste.* *Jena Zeitschr. f. Naturwissenschaft*, 1900, p. 8.

† *Das Gesetz der Wüstenbildung*, Leipzig 1912, pp. 149, 150.

Weathered sandstone, Gebel Sarabit el Khâdim.

The Canyon of Wadi Baba.



Faulted country near the head of Wadi Thal.

heaviest and most frequent near the Nile Valley and the sea, and rarer and less heavy in the tracts remote from water, especially on the Libyan plateau. But even in the heart of the eastern desert, especially among the mountains, heavy dews occur; I have observed, for instance, a litre per square metre to fall in a single night at Gebel Niqrub, over 200 kilometres from the Nile Valley and eighty kilometres from the sea. And my observations in Sinai agree with those made in 1868 and 1869 by Captain Wilson, who records* that in "December and January heavy dews at night were frequent."

The fact, too, that these hard films occur on the faces of high steep sided narrow ridges, and even on small isolated rock masses like the Dirret el Nasib, where the exposure is so great that the rocks must long since have lost their "quarry water," speaks against Professor Walther's explanation in these localities.

But though dew and light rain must be regarded as the principal agent in superficially indurating the rocks in Sinai, it is probable that the process favoured by Professor Walther also goes on side by side to some extent. Hard films may, as we know from observations at the Nile Cataracts, be formed on rocks which are yearly submerged; and in these cases it is probably the evaporation of absorbed water at the surface which produces the hard film. I noticed on the western shore of the Gulf of Suez, to the north of Wadi Araba, that limestone blocks splashed by sea water acquired a hard glossy crust resembling a coat of drab enamel paint. After the rare heavy rains, desert rocks may easily in places have absorbed sufficient water to replace the original quarry water, and thus to provide a source within the stone for the formation of a hard skin.

One of Professor Walther's difficulties in admitting the influence of dew is that, as he correctly observes, desert films are less prominent near the Nile Valley, where dews and rain are frequent, than further away, where dew and rain are rarer. This observation may be explained by remembering that it is only the water film which remains on the stone which can deposit the indurating matter; in the heart of the desert this film represents the whole fall, and all the dissolved matter is redeposited at the same place; while where the fall is heavier, the run-off removes the stony matter in solution, instead of redepositing it on the stone from which it was dissolved.

* "Ordnance Survey of Sinai," London 1869, p. 244.

Action of Plants in Resisting the Movement of Sand.

The binding action of plant roots on sand is well known, being in fact utilized in the artificial reclamation of land which has been ruined by drift sand. In West Central Sinai this action goes on naturally, the precipitation of rain and dew being sufficient to supply moisture to the roots of the hardy plants. But for the fact that a considerable proportion of its surface is covered with bushes, the great sand accumulation of the Debbet el Qeri would doubtless have advanced much further to the south than it has. It is not only the roots of the plants which are effective; the stems and leaves obstruct the driving force of the wind, producing accumulations of sand around themselves and giving rise to eddies whereby the sand, instead of being driven straight onward, is blown irregularly from place to place.

Deposition of Carbonates and Silicates from Evaporating Water.

At some points in the floor of certain wadis, as for instance the Wadi Shellal, one can observe small deposits of recently-formed conglomerate, in which pebbles and rock fragments are cemented in a hard calcareous or siliceous matrix. The origin of these deposits depends on the sporadic character of the rainfall. After a big "seil" in the wadi has left its floor covered with gravel, there is sometimes a temporary trickling spring formed at a step in the wadi floor, due to the gradual outflow of the absorbed water from the higher reaches of the wadi; this slowly percolating water has had time in its underground career to dissolve stony matter, which is redeposited among the gravel where it trickles out and evaporates, producing a conglomerate which is often as hard as granite.

TECTONIC DISTURBANCES.

West Central Sinai is one of the most intensely faulted countries in the world, and tectonic movements have had a profound influence both on its surface relief and on its economic resources. An examination of the geological map and sections on Plates I and XVII will show how important a factor tectonic movements have been in determining the structure of this district.

The most striking fault is a great dislocation which has brought the Miocene alongside the Carboniferous on the west side of Gebel Nukhul. Commencing in the north near Wadi Thal, this fault strikes in somewhat sinuous course, following a general direction a little east of south, roughly parallel to, and at an average distance of some ten kilometres from the Gulf of Suez, with an increasing throw, passing west of Gebels Abu 'Edeimat and 'Iseila, and through Gebels Sarbut el Gamal and Musaba' Salâma, along the eastern flanks of Gebels Nukhul and Samrâ, and across the junction of Wadis Baba and Shellal, whence it extends for a considerable distance further south. Its throw where it passes west of Gebel Samrâ exceeds the entire thickness of strata from the base of the Carboniferous to the top of the Miocene, and is probably not much less than 2,000 metres. This stupendous fault singles itself out from all the others observed in the district, not only by its magnitude, but also by the extremely high degree of tilting and squeezing of the beds along its course. Round about the mouth of Wadi Baba (*see* Fig. 38) the strata on the downthrow side of the fault are tilted to an almost vertical position, and the beds are pinched out to a mere fraction of their original thickness. The great fault is by no means a simple fracture, numerous minor lines of dislocation, some nearly parallel to it and others branching off at an angle, accompany the main fault; the most important of these branches are. one which extends northward from near Sarbut el Gamal up the Wadi Abu Insakar, and another which strikes south-eastward up Wadi Nukhul.

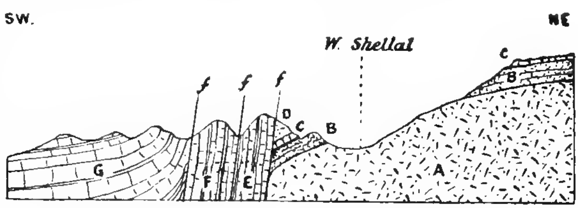


FIG. 38.—Sketch section across the great fault at the junction of Wadis Baba and Shellal. A, granite; B, Lower Carboniferous sandstone; C, Carboniferous limestone; D, Upper Carboniferous sandstone; E, Cenomanian; F, Senonian; G, Miocene; *fff*, Faults.

The first named of these two branch faults has let down the Cretaceous limestones of Gebel el 'Iseila against the Nubian sandstone of Gebel el Tih, and if followed up to the head of the wadi it is found to pass east of a remarkable group of white hills, consisting of an isolated mass of Campanian chalk, the beds of which are tilted sharply north-eastwards with a dip of fifty degrees in places. A section across

the ridge 600 metres east-north-east of my tenth camp* is shown in Figure 39, and it will be noticed that the down-thrown Campanian beds dip strongly *towards* the fault. The structure in this neighbourhood is rather puzzling, but it would seem that the Senonian has been brought down alongside the fault by sharp monoclinal folding. All along the course of this fault the Cretaceous beds of Gebel el 'Iseila, on the west side of the fault, dip strongly eastward, while the sandstones on the east side are nearly horizontal.

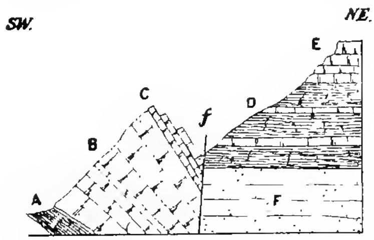


FIG. 39.—Sketch section through the fault near the head of Wadi Abu Insakar. A, grey clays; B, Campanian chalk and chalk marl with *Ostrea vesicularis*; C, harder limestone beds, with some flints; D, Cenomanian limestones and clays; E, Turonian capping the plateau of El Tih; F, Nubian sandstone; *f*, Fault.

The second branch fault, which follows the course of Wadi Nukhul, presents more normal features, throwing up the granite base of Gebel Nukhul to the level of the Upper Carboniferous sandstone which forms the broken plateau on the east side of the wadi, as shown in the sketch section in Figure 40. This fault dies out a short distance beyond the head of Wadi Nukhul.

Besides the great fault and its branches just mentioned, especially in the country to the east of them, there are a large number of other faults of lesser magnitude, of which a detailed description, besides being wearisome to the reader, would convey but little more information than is given by the geological map and sections. A glance at the map will show that most of these faults have a marked tendency to follow a direction a little east of south, but there are numerous cross faults, especially in the south part of the district, making the

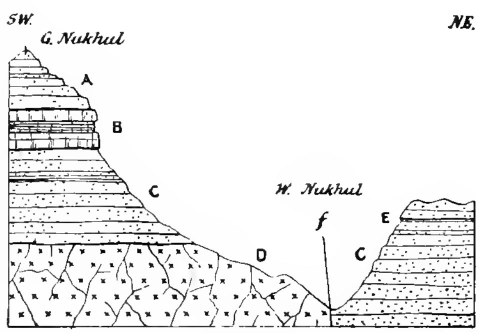


FIG. 40.—Section across the fault in Wadi Nukhul. A, Upper Carboniferous sandstone; B, Carboniferous limestone series; C, Lower Carboniferous sandstone and sandy shales; D, granites and gneiss; E, horizon of carbonaceous clays; *f*, Fault.

* The position of this camp is marked on the map on Plate I.

geological structure in some places extremely complicated. Some of the faults shown cutting across Gebel el Tih are doubtless continuous with those mapped to the south; but it has not been found possible to trace their course across the intervening sandy plain. Though these other faults are minor dislocations in comparison with the great fault first described, many of them are of very considerable magnitude, being traceable for some twenty kilometres and involving vertical displacements in some places exceeding a hundred metres. In contradistinction to the great fault, these lesser dislocations are accompanied by comparatively little bending and pinching out of the beds near the shear plane, a fact which may be partly explained by their smaller throw, but which also suggests, especially when the general horizontality of the beds is taken into account, a more sudden yielding to purely radial stresses. A typical section across one of these minor faults is shown in Figure 41. It is remarkable how frequently the drainage-lines follow closely the lines of fault, and this circumstance is easily explained by the greater ease with which the sheared-up rock along the fault must have yielded to erosion as compared with the more solid intervening portions. But it is important to note that the same fault which coincides with a deeply eroded wadi along one part of its course, may cut right across a high mountain tract in another part, and frequently at the latter place there is not the slightest change in the contour of the surface to mark the lines of fault. Nothing of the nature of a "rift" is anywhere visible; faults have governed the position of drainage lines in places, but erosion alone has removed the material from the valleys; many of the greatest wadis are absolutely independent of faulting throughout their course. And where a fault is accompanied by a change in the relief of the surface, it is merely the consequence of a difference in hardness and resistance to denudation of the rocks on the two sides, not the direct result of the thrusting up of one tract of country above the other. When the ground on the upthrow side of a fault stands up above

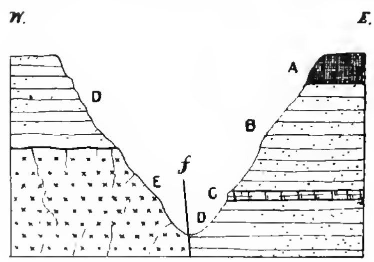


FIG. 41.—Sketch section across the fault in Wadi Hiseima. A, thick dolerite cap; B, Upper Carboniferous sandstone; C, Carboniferous limestone series, here very thin; D, Lower Carboniferous sandstone; E, Granite; *f*, Fault.

that on the downthrow side, it will always be found that this is due to the older upthrown rocks being harder and more resistant than the younger downthrown ones. Where there is no difference in the hardness of different rocks brought into contiguity by faulting, even large faults are not marked by any difference of level on the two sides; as an example of this, the lowest of the three views on Plate XXII may be referred to; the left hand portion of the high ridge there shown consists of Cenomanian beds overlying Nubian sandstone, while the longer right hand part is formed by the Eocene capping the white marls of the Senonian; thus, though the ridge is cut across by a fault having a throw of some 200 metres, the crest is practically uniform in height right across the fault.

A very interesting feature about the minor faults is their close association with the deposits of iron and manganese ores which occur at the base of the Carboniferous limestone. Every ore deposit of any magnitude in this district is on or near a fault. The importance of this observation, both as a guide in searching for ores and in giving a clue as to their origin, will be further discussed in the following section.

As to the geological epoch at which the intense faulting of Sinai took place, we have fortunately a sufficiency of observational facts to enable us to fix it within tolerably narrow limits. Since Miocene beds have been displaced by the dislocations, it is obvious that the faulting took place subsequently to the deposition of those beds. And all the Pliocene rocks bordering the Gulf of Suez are in positions which show them to occupy an eroded depression formed at the same time as, or subsequent to, the faulting. It is therefore certain that the dislocations took place about the close of the Miocene, which period, it may be remarked, coincides with that of the basaltic and doleritic intrusions of this district, and also with that to which great earth movements in other parts of the world have been assigned.

Besides furnishing the explanation of the complicated distribution of rocks of various ages in the peninsula itself, a study of the tectonic features of the coastal region of Western Sinai is of interest, when considered along with similar observations on the Egyptian side, as supplying us with some data from which to form an idea regarding the structure of the Gulf of Suez, the floor of which is hidden from geological investigation. A sketch map showing the principal

structure lines of the gulf, as far as our present knowledge goes, is given in Figure 42. It will be noticed that the Carboniferous of Sinai

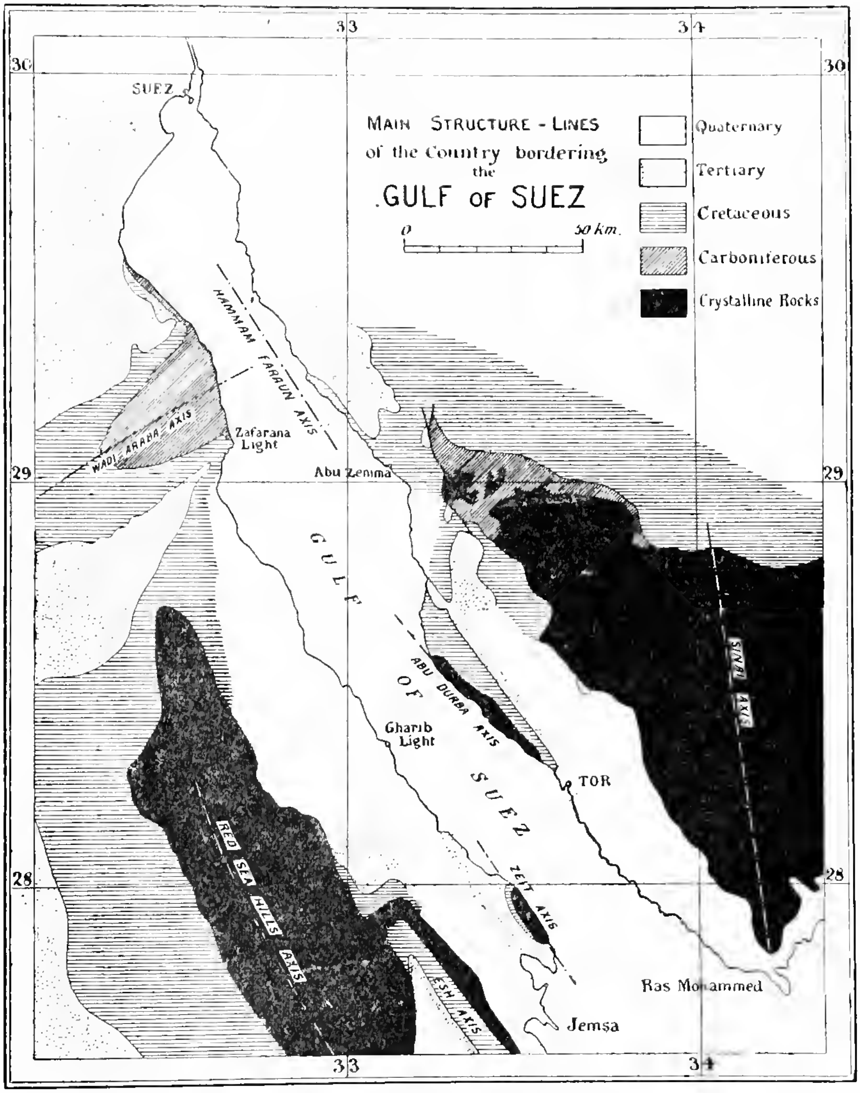


FIG. 42.—Sketch map showing the main structure lines of the Gulf of Suez.

is sharply limited to the west by the great fault which runs through Gebel Sarbut el Gamal and which has thrown down the coastal region of Sinai. This fault is so far inland that it can have had little or nothing to do with the formation of the gulf as we now know it. The gulf is in fact due to erosion of a tract characterized by sharp longi-

tudinal anticlinal folds, some of which were doubtless accompanied by fracture.*

The great fault above referred to accounts for the lateral separation of the Carboniferous of Sinai from that of Wadi Araba on the Egyptian side of the gulf. But it will be noticed that besides this lateral separation there is a distinct difference of latitude between the two exposures; the Carboniferous tract of Wadi Araba lies considerably north of that of Sinai, giving the appearance on the map of a north-and-south shift between the two masses. The explanation of this distribution is easily explainable by the existence of a sharp anticlinal axis, probably accompanied by fracture, near the coast parallel to Gebel Hammam Faraûn, and of another anticlinal axis, in a direction nearly at right angles to the former, passing down the Wadi Araba. The presence of the Wadi Araba axis is extremely well marked by the anticlinal structure of its floor. The existence of the Hammam Faraûn axis may be inferred from the structure of the coastal hill-range, the rocks of which dip inland; the warm springs which occur on the sea shore at the north end of Gebel Hammam Faraûn afford further evidence of a probable fault near the coast.

ORE DEPOSITS.

The ore deposits of West Central Sinai consist of oxides of manganese and iron. The principal mineralogical species, which sometimes occur pure, but are more often found in intimate mixture with each other in various proportions, are:—

Pyrolusite, or soft manganese ore, MnO_2. This mineral, which is the most valuable ore of manganese, containing sixty-three per cent of the metal, most commonly occurs massive, but frequently takes on a fibrous form. The fibres have a silky lustre. Pyrolusite is dark grey to black in colour, with a black streak, and so soft as to blacken the hands readily. The specific gravity is 4·8.

Psilomelane, or hard manganese ore, a mixture of MnO_2 with varying proportions of other oxides, usually those of potassium and barium. It contains about fifty-five to sixty per cent of manganese.

* For remarks on the origin of the Gulf of Suez, see my two short papers in the "Geol. Mag.," Dec. V, Vol. VII, pp. 71-76, 1910, and Vol. VIII, pp. 1-10, 1911.

Psilomelane occurs massive, often with botryoidal surfaces. It is usually of a bluish-black colour, dark grey on fracture, of great hardness, and readily strikes fire under the hammer. Its specific gravity averages about 4·5.

Wad, a brown to black soft powdery mineral, probably an impure hydrated manganese oxide.

Hæmatite, red oxide of iron, Fe_2O_3. This mineral, which when pure contains seventy per cent of iron, usually occurs in masses having a botryoidal or mammilated surface and an internal fibrous structure. Its hardness and specific gravity vary considerably, but the purer forms are harder than calcite, and have a specific gravity exceeding 5·0. More common than the pure hæmatite is a soft earthy ochreous variety, probably containing a considerable admixture of limonite, the hydrated form of ferric oxide.

The deposits of iron and manganese ore in this part of Sinai are always found at one particular geological horizon, *viz.* the base of the Carboniferous limestone.* Though not true beds, the ore deposits possess in general a marked bed-like character, extending for considerable distances along the same level. The principal localities in which the deposits have been found are (1) at Gebel Um Rinna; (2) in and near the Wadi Kharig; (3) on both sides of Wadi Baba near Bir Rekis; (4) in Wadi Nasib; (5) round the heads of Wadi Abu Hamata and its tributaries; (6) in the hills of the Um Bogma district; and (7) in the neighbourhood of Bir Um Hamd. In general, the presence of the ore band is clearly marked in the scarps by its dark colour, which enables it to be followed round for miles; but in some places the outcrop is covered up by debris. The facilities for an examination of the ore deposits have been much increased, since their discovery in 1898 by the late Mr. Barron of the Geological Survey, by the numerous excavations made by prospectors with a view to exploitation of these mineral resources. I shall first here set down the detailed observations I have been able to make concerning the conditions of concurrence of the ores at different places, and then offer some general remarks as to the conclusions which can be drawn from these observations, regarding the mode of origin of the deposits.

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* Thin beds of ore are also occasionally seen at the top of the limestone, and in the neighbouring sandstone; but these occurrences are too small in thickness and extent to be of economic importance.

Ore Deposits of Gebel Um Rinna.*

The triangulation cairn on Gebel Um Rinna, 592 metres above sea, stands on a headland capped by a bed of hard manganese ore about a metre thick. A section through the headland is shown in Figure 43. On the west, the ore bed is cut off by a steep drop into the valley below, but to the east the ground is covered by debris of manganese ore, and outcrops of ore occur round the foot of the limestone ridge which runs north-eastward from the cairn.

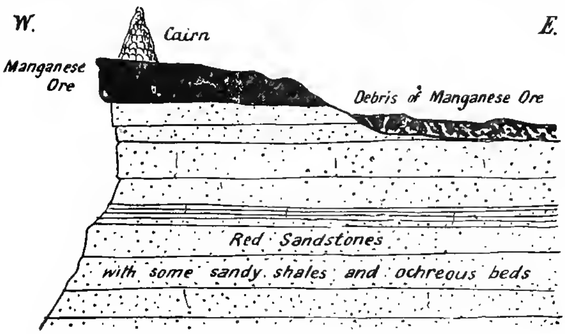

Fig. 43.—Section through the triangulation cairn on Gebel Um Rinna.

About 300 metres east of the cairn there is a large ancient excavation, cutting like a tunnel through the neck which separates the heads of two wadis (*see* the sketch map, Fig. 44). This underground excavation is some twenty metres wide by one to two metres high, and extends for a length of about fifty metres. The roof, which has partly fallen in, consists of thick beds of brown crystalline dolomite. No pillars have been left to support the roof. At the faces of the excavation, manganese ores, hæmatite, and ochre occur in strings and patches, and here and there are traces of malachite. It is evident that malachite was the ore sought by the ancient miners, because the immense masses of manganese ore exposed at the surface are left untouched. The mine has served in modern times as a hyæna den, and contains great heaps of camel bones.

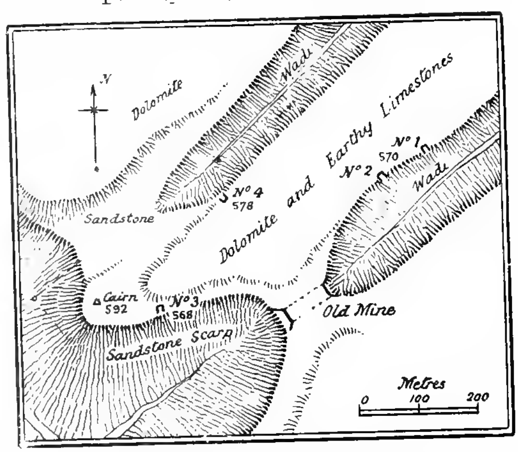

Fig. 44.—Sketch map showing excavations at Gebel Um Rinna. Levels above sea are figured in metres.

* The ores collected by Barron from "Wadi Malh" were doubtless from this locality: Wadi Malha drains the eastern flanks of Gebel Um Rinna (*see* p. 78).

Besides the ancient mine above described, there are four excavations into the face of the hill made recently by prospectors, and in these the distribution of the ore is well seen. In the sketch map above,

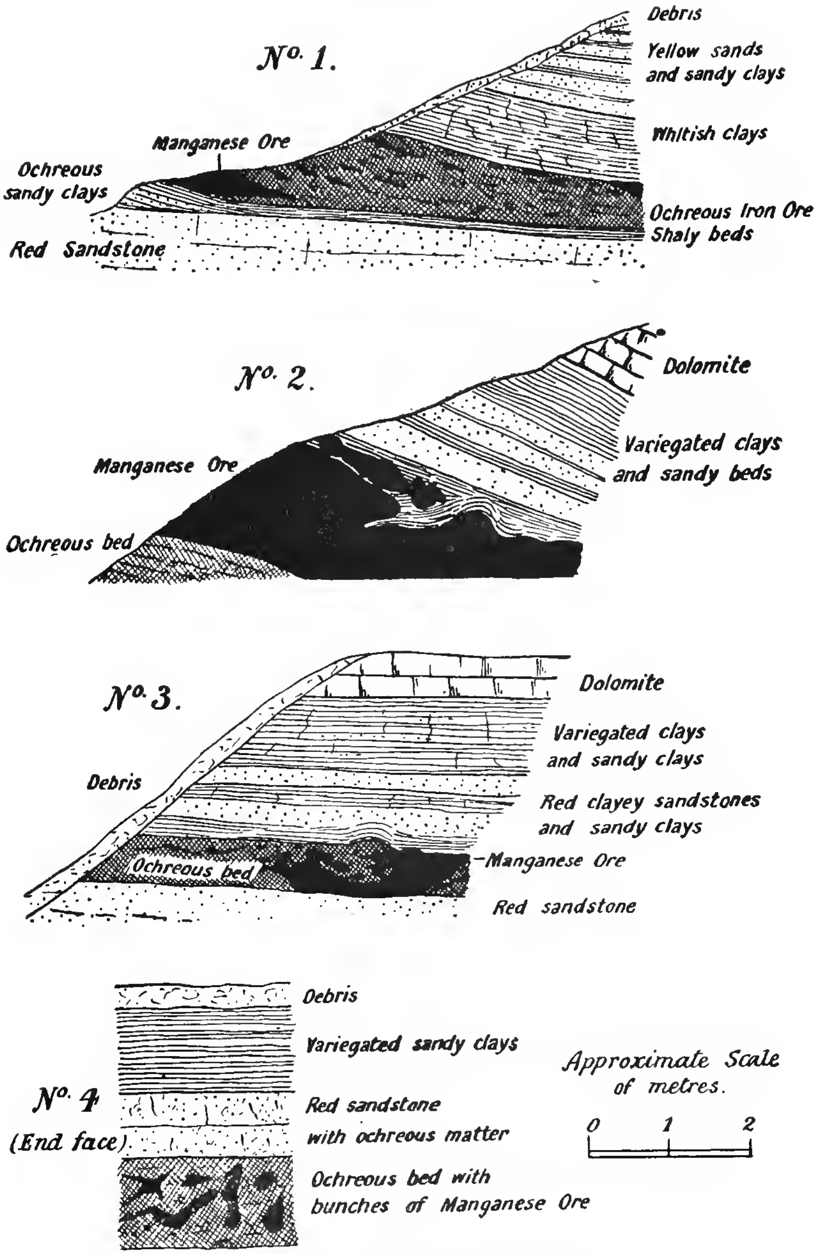

FIG. 45.—Exposures of manganese ore deposits, Gebel Um Rinna. (For positions of the different exposures see the sketch-map, Fig. 44).

these excavations have been numbered 1 to 4; the nature of the exposure in each of them is shown in Figure 45, reproduced from detail

sketches taken on the spot. It will be noticed that the ore bed is very irregular, consisting of masses and bunches and strings of psilomelane of specific gravity 4·2, scattered in a bed of earthy ochreous iron ore. The floor of the ore bed is of red sandstone, and thin clayey and sandy beds separate the ore from the overlying dolomite. The extent of the bed is very difficult to estimate, as the slopes are covered by debris which hides the ore from observation except at the excavations and a few other points.

Ore Deposits of the Wadi Kharig.*

On the western side of the little Wadi Kharig, about a kilometre above its point of junction with Wadi Baba, there is an ancient mine containing iron and manganese ores, and outcrops of ore occur for 500 metres or so along the side of the wadi in the neighbourhood of the mine. The mine is an irregular underground excavation, about a hundred metres in length by ten metres wide and two metres in average height. A sketch section across it is shown in Figure 46. The

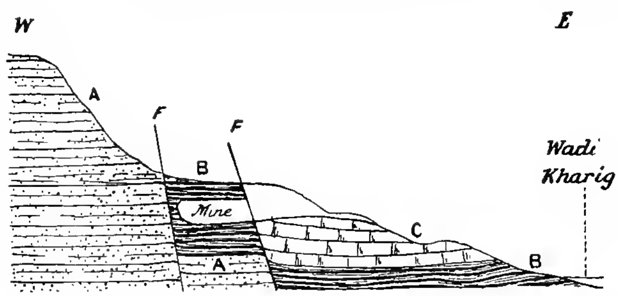

FIG. 46.—Section through the ancient mine in Wadi Kharig. A, Lower Carboniferous sandstone; B, sandstones and clays with bands of ochre and earthy iron and manganese oxides; C, Carboniferous limestone and dolomite; F, faults.

working faces show alternations of variegated sandstones and sandy and gypseous clays, with bands of ochre and earthy iron and manganese oxides. The total thickness of the ore beds is about half a metre. There are heaps of earthy ores, and some more solid-looking ones, outside the mine, but the general character of the ore is distinctly inferior to that of Um Rinna.

As will be seen from the section above, the ore beds do not extend into the scarp, but are cut off by a fault close to the back of the mine, while at least one other fault cuts through the mine itself. Slicken-

* Wadi Hallig of Barron.

sides are well seen in the sandstone at the fault plane. The limestone beds, with a little ore in places at the base, can be seen again higher up the scarp beyond the fault. On the east side of the wadi there is a similar slipping down of the beds at the face of the scarp.

The total quantity of ore in the Wadi Kharig appears to be by no means large. The ferruginous and manganiferous deposits only occur in patches below the limestone series, not as a continuous band; there are miles of the limestone-sandstone junction visible without any appreciable amount of ore.

Here, as at Um Rinna, the mineral exploited by the ancient miners cannot have been iron or manganese ore, for these ores have all been left. It is probable that here also copper carbonate was the substance extracted; I picked up a small fragment of malachite near the mine, though I saw none in the mine itself.

Ore Deposits in the neighbourhood of Bir Rekîs.

About two kilometres south of the old mine in Wadi Kharig above described, manganese and iron ores are to be found in some abundance in the hills on both sides of Wadi Baba round about the well called Bir Rekîs. The most important deposits so far discovered in this neighbourhood occur in the long semi-detached hill north-east of Bir Rekîs. From the map on Plate I it will be observed that this hill lies between two faults. The ore deposits are exposed in the face of the hill at a height of from thirty to sixty metres above the wadi floor, the ore band rising gradually from north to south. In this hill the Carboniferous limestone series, at the base of which the ore deposits are found here as elsewhere, is very thin, having mostly disappeared by solution; and even the ore band which marks the limestone horizon was not very conspicuous till the obscuring debris was removed by the excavations of prospectors. In the western face of the hill there are four excavations, which for convenience of reference may be numbered from north to south, placed at intervals over a length of about 300 metres, and driven some fifteen metres into the hill face. The sections exhibited in these four excavations are shown in Figure 47. In the northernmost section (No. 1), the ore bed is cut off by a small fault close to the hill face, and the remainder of the excavation is entirely in yellowish semi-crystalline limestone, overlain by yellow and

white clays and marls; one or two small masses of ore occur in the limestone close to the fault. In No. 2 section (about 200 metres south of No. 1), the crystalline limestone has entirely disappeared, its

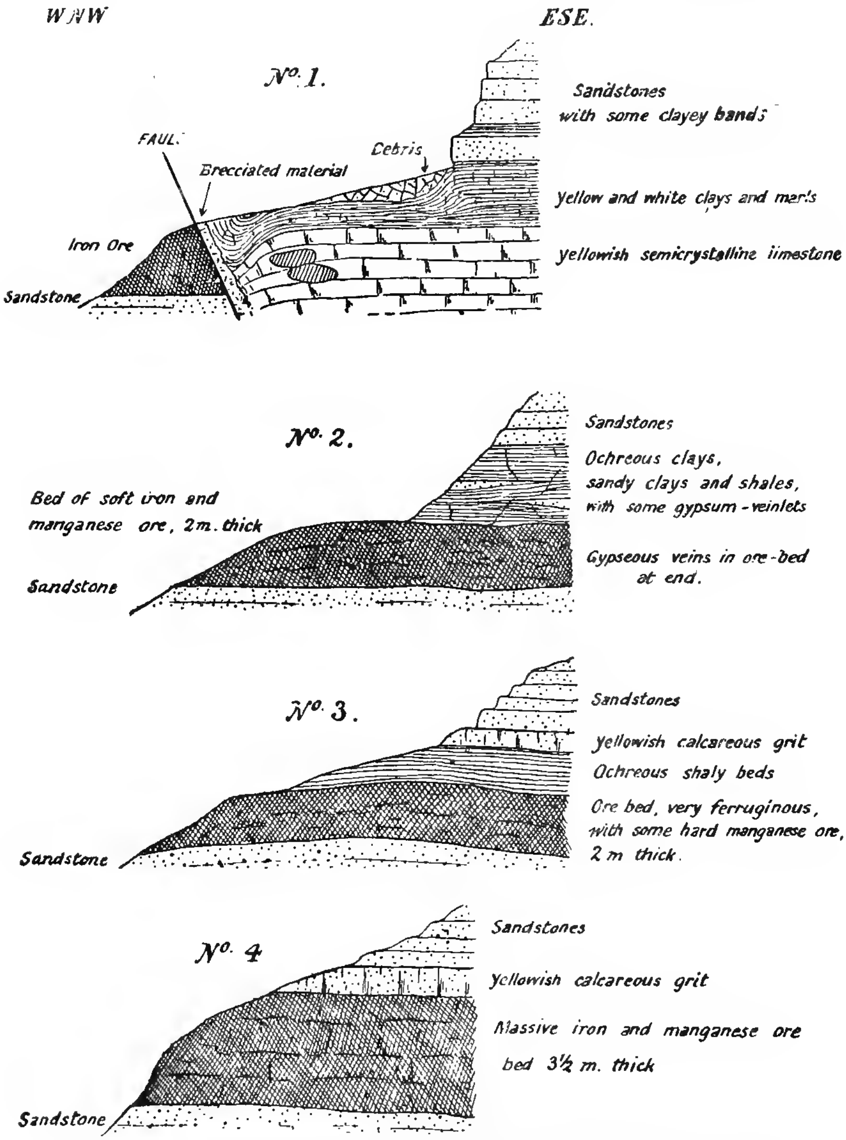

Fig. 47.—Sections through the ore deposits in the western face of the hill on the east side of Wadi Baba, near Bir Rekis.

place being taken by a persistent bed of iron and manganese ore two metres thick, with sandy clays and shales above; small veins of gypsum occur both in the ore bed itself and in the overlying clays and

shales. In No. 3 section the ore bed is still two metres thick, overlain by ochreous shaly beds, which in turn are separated from the upper sandstones by a stratum of yellowish calcareous grit. In section No. 4 the ore bed has thickened, the overlying shales have disappeared, and the yellowish calcareous grit now separates the ore bed itself from the upper sandstones; the entire Carboniferous limestone series is thus here represented by some four metres of strata, of which three and a half metres are occupied by the iron and manganese ores and the remaining half metre by calcareous grit.

South of the No. 4 section I could only trace the out-crop of the ore bed for a short distance along the debris-covered slope; but a shaft put down by prospectors about fifty metres back from the face and 120 metres south of section No. 4 passed through ore of the same character as that seen in the face, and ores have likewise been found in a number of excavations on the eastern side of the hill. It therefore appears most likely that the ore deposits extend right through the hill. Subsequently to my examination of this locality, I was informed by M. Gripari, who was making exploratory excavations, that in one place on the eastern side of the hill the ore deposit was found to be in contact with granite. I was unable to find time to visit this interesting exposure; as will be seen from the map (Plate I) the granite has been thrown up to the east of the hill by a fault which extends far to the south, so that the association is easily explained.

In the hills on the opposite side of Wadi Baba to the foregoing, ore deposits are visible at numerous points, and some trial excavations in them have been made by prospectors, especially near the head of the little Wadi Abu Maghara. I did not examine these exposures in detail, but the ore appeared, so far as I could see, to occur in patches, always at the same horizon (the base of the limestone series), and always in close association with one or other of the numerous faults which traverse this region.

Ore Deposits in and around Wadi Nasib.

As one proceeds up the Wadi Nasib from Wadi Baba, the sandstones and limestones of the low hills on the western side are observed to be let down by the great fault which runs approximately along the drainage line, while a high scarp, with granite at its base, bounds the wadi on the east. No ore is seen till Bir Nasib is approached,

when some deposits of insignificant magnitude occur at the base of the limestone. Just beyond the well there is a mass of ore in the wadi itself, and some pocket-like deposits occur in the hills to the east. The situation of these deposits, near to one of the best water sources in the peninsula, is a feature favourable to exploitation; but the general impression I formed (I did not examine the exposures in detail) was that the ore hereabouts is more sporadically distributed and the deposits are less in thickness and extent than at many other places.

Ore Deposits of Waḍi Abu Hamata and its Tributaries.

High up in the steep scarps which shut in the heads of Wadi Abu Hamata and its two tributaries, the Wadis Abu Thor and Himeirâ, bed-like deposits of iron and manganese ores can be traced for long distances at the base of the Carboniferous limestone series, and in some places, especially in the neighbourhood of faults, the ore deposits attain a considerable size and thickness. Prospecting has been carried on at various points, especially near the narrow neck which divides the head of Wadi Abu Thor from that of Wadi Abu Hamata. I did not find time to examine the excavations, but from the masses of ore piled outside them it would appear that this locality is one of some richness in manganese and iron. Being situated at high levels and approachable only by steep climbs from the gorge-like wadis, the ore deposits are somewhat difficult of access; but they are not more so than were the mines of Um Bogma before special roads were constructed by the mining engineers.

Ore Deposits of the Um Bogma District.

The manganese and iron ores of the Um Bogma district occur as irregular deposits, with a strong tendency to tabular and lenticular forms, at the base of the Carboniferous limestone series. The ores crop out in the faces of the steep scarps which bound the irregular plateau-like hills; but the numerous excavations made by prospectors, both in the form of headings driven into the faces of the hills and as shafts sunk to the ore horizon from the plateau surface, furnish even more instructive exposures than the natural ones. The general distribution of the ores of Um Bogma is shown in the large scale map of the

district on Plate XXIII. The principal deposits occur in four groups of hills, which for convenience of reference have been named on the map as the Central, North, East, and South Hills respectively.

Central Hills.—A bed-like deposit of ore, averaging about two metres in thickness and attaining as much as four metres in places, extends through the greater portion of the mass of the Central Hills. Headings driven into the ore bed from the two sides of the hill, in some cases to distances of over forty metres, mostly show the ore to persist in a nearly horizontal sheet, with sandstones below and ochreous sandy clays above; the sandy clays are in turn overlain by yellow marls and crystalline dolomite, as shown in the type section in Figure 27 on page 153. The ore in this locality is mostly of a rather soft character, varying from almost pure pyrolusite to an ochreous hæmatite; but there is also some psilomelane. As a general rule, to which, however, there are some exceptions, the deposits appear to be thickest and richest in manganese near the faces of the scarps, and to become more ferruginous further in. On looking at the map, it will be noticed that this general richness at the scarp faces can be correlated with proximity to faults, suggesting that faulting has had something to do with the genesis of the deposits; and this suggestion is strengthened by the fact that whenever an exception to the general rule of greatest richness near the face is encountered, a subsidiary fault is usually observable at or near the place of enrichment. It should be mentioned that only the more important and persistent faults are indicated on the map; there are numbers of others which are too small to be clearly shown on the scale employed.

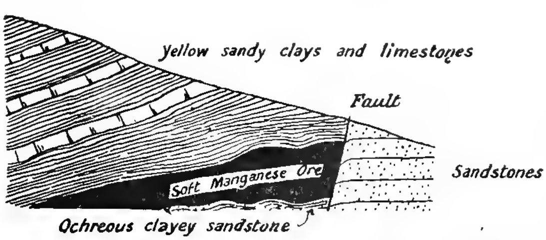

FIG. 48.—Section of ore deposit in hill side, east-south-east of the main triangulation point on Gebel Um Bogma.

The exposures examined in the Central Hills are numerous, and need not all be described in detail. The above remarks sum up the general result of the examination, but I may here mention a few exposures which have a particular interest as bearing on the origin of the ore. The first of these, shown in Figure 48, is an excavation in the eastern face of the hill about 600 metres east-south-east of the main

triangulation point. It will be seen from the figure that the ore does not crop out on the hill side at this point, but is cut off by a fault against the sandstone, and the deposit is thickest close to the fault. Incidentally, this section indicates that ore may sometimes be found by driving into the hills even when no evidence of its presence appears on the hill face.

Another section which clearly exhibits the association of ore-deposits with faulting occurs on the eastern side of the track which leads from the mines to Wadi Shellal. Here (*see* Fig. 49) a fine mass

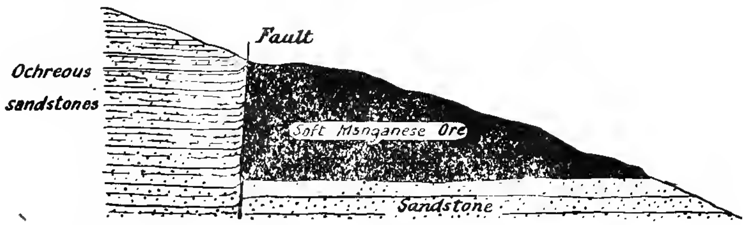

FIG. 49.—Section of ore deposit east of the road to Wadi Shellal.

of ore has been followed into the hill for twenty-seven metres, when it is cut off by a fault, and a further drive of thirty-six metres into the hill is entirely in ochreous sandstones. The ore mass increases in thickness to over three metres at the fault; it then ends as sharply as if cut by a knife, and the ochreous sandstones against it are bent upwards for a few centimetres at the fault-plane, showing the downthrow of the fault to be to the east. The ore mass, if it extends on the other side of the fault, would probably be found by sinking to a few metres depth in the floor of the heading.

On the opposite side of the ravine to the exposure last described, an excavation made in the ore bed has run into a curious natural cavity; the suggestion here is that the ore has been deposited in a chamber formed by solution of the limestone beds, and that the deposition has not progressed sufficiently to fill the chamber.

On the little plateau on which the main triangulation point stands, a shaft has been sunk through the limestone series to the ore bed. The material brought up and piled round the opening shows that after passing through the red and yellow crystalline dolomites which form the plateau, the shaft penetrates into ochreous clays and bands of soft ore; but the special interest of this excavation is that veinlets and strings of pyrolusite are found penetrating the dolomite, evidently as the result of deposition from manganiferous solutions penetrating the smashed-up rock.

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penetrating the smashed-up rock.

A heading driven into the north-west corner of the Central Hills shows the deposit there to be poorer than near the centre ; the ore-bearing stratum consists of ochreous red sandy clays, with green patches and nodules of manganese ore, the latter comprising only about five per cent of the whole bed. It will be noticed from the map that the two faults on either side of the Central Hills begin to diverge considerably in the latitude of this point.

East Hills.—The northern scarps of the eastern group of hills exhibit an almost continuous outcrop of ore at the usual horizon. A typical section, exposed in an excavation north of the road which leads to the pass at the head of Wadi Hasania, is shown in Figure 50.

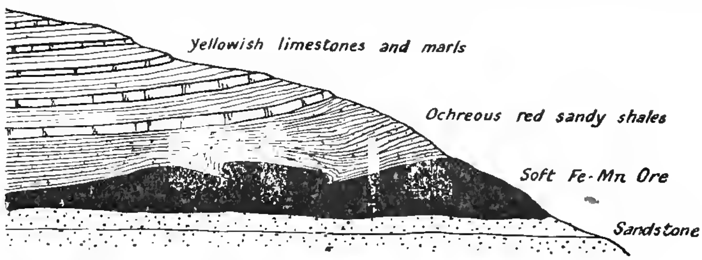

Fig. 50.—Section of ore bed on north flank of East Hills.

Two shafts, sunk one near the road and another near the north end of the plateau, have each passed through dolomite and shales into soft manganese ore. The deposit appears thus to be continuous through the north portion of the hills, and here again it is observable that the maximum thickness is near a fault, for to the north of the head of Wadi Um Sakran the ore bed attains a thickness of four metres, and contains numerous hard patches very rich in manganese.

North Hills.—Probably owing to their greater distance from the temporary headquarters of the prospectors, the North Hills have not been prospected so thoroughly as the Central and East Hills, and the natural exposures are not so extensively supplemented by artificial excavations. But, as will be seen from the map, the ore deposits can be traced round almost continuously, and the North Hills probably contain deposits little if at all inferior to those of the Central Hills. The fact that the North Hills are cut through by at least three well defined faults, considered in conjunction with the observed greater richness of the ore near faults in the more highly prospected Central Hills, is a favourable one from the economic standpoint.

South Hills.—Highly ferruginous beds, with patches of hard and soft manganese ore, can be traced round a large portion of the south group of hills, and are likewise noticeable in the western part of the narrow ridge which connects the group with the Central Hills. But the excavations made by prospectors show that the ore deposits are here thinner and poorer in manganese than those of the other groups of hills above mentioned; further, they do not appear to persist through the hill mass, but to be largely peripheral.

On the western side of the hill, a little north of where the track ascends, an excavation carried for a distance of thirty-seven metres into the hill side exhibits the section shown in Figure 51. The ore-

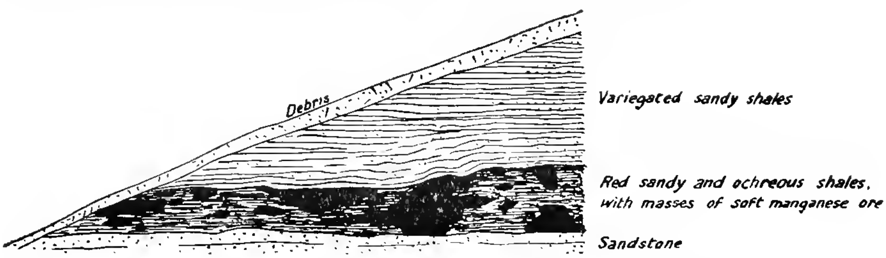

FIG. 51.—Section of ore deposits on the eastern side of the South Hills, north of the track.

bearing bed, about two metres thick, consists of red sandy and ochreous shales with patches of soft manganese ore, and is overlain by variegated sandy shales. Though the ore-bearing bed here persists right to the end of the excavation, it does not extend through the spur of the hill to the other side, for a second excavation made on the eastern side

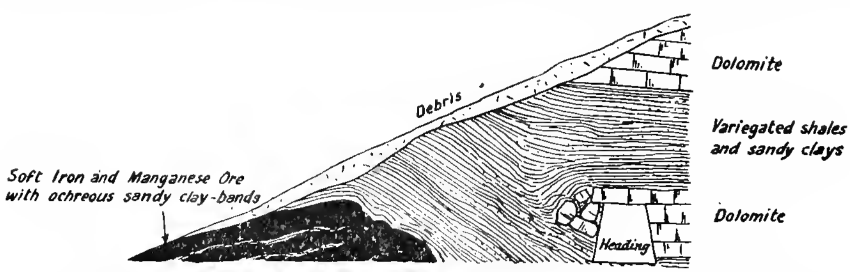

FIG. 52.—Section exposed in an excavation on the western side of South Hills, north of the track.

of the hill shows the ore mass there to come to an end about eleven metres from the face; a further five metres of open cutting passes through variegated shales and sandy clays into crystalline dolomite (*see* Fig. 52), and a heading driven fourteen metres into the hill in a

direction at right angles to the cutting is entirely in dolomite and shales.

A third excavation has been carried about twenty-eight metres into the western face of the hill at a point some half a kilometre south of that last mentioned; here a bed of ochreous shales containing patches of soft manganese ore was passed through at the entrance, but the continuation of the heading is a brecciated mass of shales and grits with included lumps of dolomite (*see* Fig. 53). The appearance both

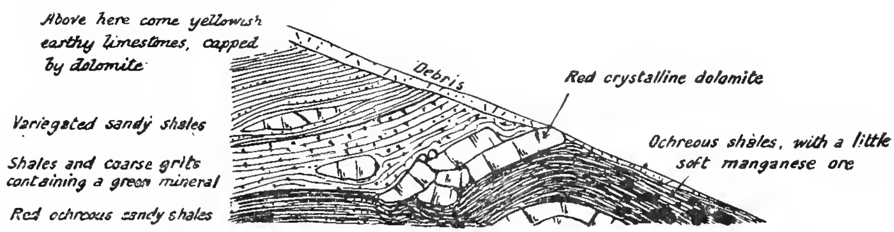

FIG. 53.—Section exposed in an excavation on the western side of South Hills, about half a kilometre south of that shown in Fig. 52.

here and at the foregoing section is one of faulting near the face of the hill; but it is difficult to trace the course of the faults owing to the surface being covered with debris. Much of the hard ore seen at various points round the hill has more the appearance of conglomerated debris than of an outcropping solid bed.

Ore Deposits near Bir Um Hamd.

In the hill due north of Bir Um Hamd, to the south of Wadi Shellal, ore deposits crop out at a high level, and can be traced round the base of the limestone series which caps the hill. Other deposits occur at lower levels, but at the same geological horizon, on the western side of the Wadi Um Seyelat, a little feeder of the Wadi Shellal. This district, as will be seen from the map on Plate I, is one of much faulting, the hill first mentioned being completely enclosed by four faults, while the deposits in the Wadi Um Seyelat are on the downthrow side of one of the four. A number of excavations have been made by prospectors in this locality; I did not examine the exposures, but from the black masses of excavated material there appears to be a considerable amount of ore here present.

Origin of the Manganese and Iron Ores.

From the observational data recorded on the geological maps and in the foregoing descriptive account of the ore deposits at various points, we may draw the following general conclusions relative to the manner of occurrence of the manganese and iron ores of West Central Sinai :—

1. The ores invariably occur at the same geological horizon, namely, the base of the Carboniferous limestone series.

2. The ore bodies consist of irregular deposits, with a strong tendency to tabular and lenticular forms.

3. The ore deposits are only found in the immediate neighbourhood of faults, and are thicker and richer in manganese at points close to the faults than elsewhere.

4. Wherever ores occur, the dolomitic limestones have partially or wholly disappeared, their place being taken by ochreous sandy clays and shales.

5. Where a part only of the limestone series has disappeared in the vicinity of ore deposits, it is always the lower part of the series which has vanished, the upper beds being left.

That the ore deposits are not true beds is evident from their discontinuous character and from their rapid variations in thickness and composition. They are of secondary origin ; that is, they were formed by chemical action subsequently to the deposition of the rocks in which they occur.

The constant association of the ore bodies with faults, and their greater thickness and richness in manganese close to the faults, show that faulting has in some way controlled the formation of the ores. Since faults almost invariably form fissure-like passages along which underground waters can circulate more freely than in solid rocks, it is strongly suggested that the ores have originated through the agency of such underground waters. This enables us to fix the age of the deposits as not earlier than the Miocene period, in which the faulting

took place. The partial or total disappearance of the dolomitic beds of the Carboniferous limestone series, at all points where ore deposits are found, indicates that a possible source of the ores may have been the dolomites themselves. To test whether the dolomites, which are typically of pink colour, contain enough manganese to account for the formation of the ores in this way, analyses of six typical specimens of dolomite, collected from various points remote from actual ore deposits, were made in the Government Analytical Laboratory, with the following results :—

Locality.	SiO_2 and insoluble.	Fe_2O_3	CaO	MgO	MnO	CO_2	Total.
Wadi Shellal, near Naqb Budra (lower beds) ...	1·08	2·11	31·32	20·37	0·27	45·28	100·43
Wadi Shellal, near Naqb Budra (upper beds) ...	3·18	2·49	30·20	20·07	0·33	44·33	100·60
Between Wadis Lahian and Zobeir	1·22	1·58	30·88	20·40	0·19	45·16	99·43
Plateau above mouth of Wadi Shellal...	0·50	2·19	31·52	19·82	0·35	44·09	98·47
Gebel Nukhul, lower beds	5·36	1·22	29·72	19·65	0·08	44·54	100·57
Gebel Nukhul, uppermost bed	8·12	2·06	28·60	18·48	0·24	42·51	100·01
Mean of six specimens...	3·24	1·94	30·38	19·80	0·24	44·32	99·92

These analyses show that the dolomites contain on an average about 0·24 per cent of MnO, or 0·30 per cent of MnO_2, the form in which the manganese mostly occurs in the ores. If we take an average thickness of twenty metres for the dolomites before solution (the thickness actually observed exceeds this at Gebel Nukhul and elsewhere), we have a total content of about 0·17 ton of MnO_2 per square metre covered by the beds, or sufficient to form a continuous layer a little over three centimetres thick if all the MnO_2 were extracted. It is obvious that the dolomite is thus a possible source of the ore deposits ; but if it is the only source, and if the dolomite was not originally richer in manganese near the deposits than elsewhere, a con-

siderable degree of segregation and concentration must have gone on to form the existing thicknesses of ore around the faults, for a single square metre of pure manganese ore a metre thick represents the total possible yield of some thirty square metres of the dolomitic strata. So far as I have been able to ascertain, there is no other likely source for the ores; for although the basal igneous rocks contain small amounts of manganese oxide, there is no proof that the igneous rocks have been richer in manganiferous constituents below the ore deposits than elsewhere, and it is not easy to see why, if the manganese were derived from the basal rocks, the ores should have been deposited only at the base of the limestone series, and not in the sandstones and shales which intervene between the igneous rocks and the limestone series.

As to the source of the waters which dissolved the dolomites and deposited the ores, it is clear that they came from below, because where only a portion of the dolomites have disappeared it is always the lower beds which have vanished. Had the waters been ordinary atmospheric waters, percolating from above, we should have expected the upper dolomites to have been first attacked. The subterranean waters, coming possibly from great depths up the fault fissures, may have been intensely active solvents by reason of their high temperature and pressure.

The process by which the ores have been formed appears therefore to have been as follows. Intense faulting during the latter part of the Miocene period gave rise to an up-flow of heated subterranean waters in the fault fissures. These waters, acting on the dolomitic limestones, dissolved the carbonates of lime and magnesia which form the main constituents of the dolomite, leaving the less soluble carbonates of iron and manganese, and the siliceous impurities, largely unattacked. The carbonates of iron and manganese were subsequently oxidized, and underwent a process of segregation to form the ore bodies near the faults, while the siliceous matter forms the sandy shales which nearly always occur above the ores. It may be remarked that these shales have all the appearances of being secondary deposits like the ores themselves; they seldom show any persistent true bedding planes, but are foliated round the ore bodies and full of lenticular sandy and ochreous masses, while in some places they contain lumps of unaltered dolomite.

Segregation has apparently not been entirely confined to places where the dolomite has undergone actual solution, for two samples of dolomite collected from above the ore bed at the head of Wadi Hasania, the one from a metre and the other from half a metre above the ore, yielded the following results on analysis :—

	SiO_2 and insoluble.	Fe_2O_3	CaO	MgO	MnO	CO_2	Total.
1 metre above ore	0·54	0·82	32·00	19·41	0·71	44·75	98·23
½ metre above ore	0·88	10·72	27·96	16·75	1·20	40·32	97·83

showing a very distinct increase in iron and manganese content as the ore is approached.

Though there can, I think, be no doubt as to the origin of the ore being solution of the dolomites by water ascending fault fissures and concentration of the manganese and iron content in the vicinity of the faults, there are one or two points which still require clearing up before our knowledge of the process of formation of the ores can be considered at all complete. Why did the segregation take place near the faults? What became of all the dolomite removed in solution? How is it that considerable ore deposits occur in small areas surrounded by faults, where the amount of original dolomite included within the faults cannot have been sufficient to supply the quantity of manganese and iron oxides in the ore beds? And how is it that one does not observe any perceptible quantity of manganese ores in the alluvium of the wadi beds, seeing that many of the drainage lines run along fault-lines and ores are exposed in thick beds on either side? To most of these questions I can attempt no answer; but regarding the last, I think a sufficient explanation may be found in the fact that the ore beds, though very conspicuous, constitute only a very small proportion of the total mass which has been eroded away, and the ore fragments, being heavy, will have sunk in the lighter sands and gravels which form the bulk of the alluvium.

From the economic standpoint, the main importance of a study of the origin of the deposits is as to how the hypothesis formed may be utilized in the exploitation of the ores and as a guide in searching for undiscovered masses. It may be accepted as absolutely certain that faults have been a controlling factor in the ore deposition; and

that although faults occur without ore deposits, there is no instance of ore having been observed except in the immediate neighbourhood of faults. The location of faults in and near known ore masses will therefore be the best way of tracing out the directions of greatest richness of the ores. And if it be desired to search by boring for deposits hidden by overlying rocks, boring should be undertaken at places which are near to faults, and where in addition the overlying strata are thin. On these two points the geological map and sections will afford valuable aid. I would emphasize that only the major faults are indicated on the map, and that small faults may be found to be just as influential factors in ore deposition as great ones; so that in prospecting a look-out should be kept for minor dislocations.

HYDROCARBONS AND OIL.

Boring for oil was commenced in August 1910 at Gebel Tanka, close to the shore and at the foot of the Eocene scarp referred to on page 127. The site was selected in consequence of a dark mud-like substance containing a heavy oil being observable on the sea bottom at low tide along the shore in this locality. The work of boring was continued till the end of February 1913, when the enterprise was abandoned for lack of capital. Three bores were put down. The most northerly of the three was the deepest, being carried down to a depth of 2,930 feet, passing right through the Cretaceous strata and into the Nubian sandstone. The next bore, a few metres further south, was continued only to 510 feet. The southern boring, about 160 metres distant from the northern one, reached 2,292 feet, and did not penetrate the Nubian sandstone.

The records of the boring operations, consisting of the logs in which each day's work was entered with notes on the strata passed through, diagrams of the bores showing the casings and the depths at which oil and water bearing strata were met with, and an incomplete set of samples taken from various depths, have been kindly placed at my disposal by the Mines Department. Unfortunately the records are too imperfect to furnish a very clear account of the geological structure of the district. The notes on the strata passed through were made by a driller unfamiliar with geology, and the samples frequently differ considerably in character from the description

given in the logs; the samples themselves consist of pounded-up material pumped from the bores, and give no information as to the "lie" of the strata. For those portions of the bores which are represented by samples, I have considered it advisible to disregard the driller's description of the rocks traversed, and to draw conclusions only from the samples themselves; but where no samples have been collected there is no other course possible than to accept the driller's notes as to the strata.

The beds passed through by the northern (deepest) bore appear to admit of summarizing as follows from above downwards:—

	Thickness in Feet.
Grey marls and shales with some limestones ...	700
Brown earthy limestones and marls	665
Chalk and chalk marls	220
Grey marls	100
Chalk and chalk marls	340
Grey marls and shales with *Ostrea Mermeti** ...	315
Black sand and water	5
Sandstones, clays and red marls	585
Total	2,930

As regards the geological age of the beds, the uppermost strata in the bore are probably Eocene, for Eocene fossils have been found in the scarp close to the mouth of the well. The grey marls and shales with *Ostrea Mermeti* are Cenomanian. The intervening strata are probably mostly Senonian, but of this there is no sure evidence. The Senonian in this part of Sinai typically consists of white chalk and chalk marl, so that we need have little hesitation in placing the beds of this character in that division; but the "grey marls and shales with some limestones" and the "brown earthy limestones and marls," which overlie the chalk and chalk marls, may be either Eocene or Cretaceous, there being nothing to guide one as to which division to place them in. The lowest strata in the well, sandstones, clays, and red marls, doubtless belong to the Nubian sandstone group. If we provisionally put the Eocene-Cretaceous limit at the top of the highest group of chalk and chalk marls, the thickness of the various formations passed through by the boring are:—

		Feet.		Metres.
Eocene		1365	=	416
Cretaceous	Senonian	660	=	201
	Cenomanian	315	=	96
Nubian Sandstone		590	=	180

* Two specimens of this typical Cenomanian shell were brought up from a depth of about 2400 feet in the boring.

The thicknesses of the Senonian and Cenomanian here shown are much inferior to those exposed in the same formation further east; this may be easily explained on the assumption that the beds have been pinched out by a fault running nearly along the coast, an assumption which is warranted by certain other facts, such as the encountering of hot water in the bore. It should be emphasised that the borings give us no evidence whatever as to the inclination of the beds, and though they are shown horizontal in Figure 54 we have no proof that this is the case.

For the economic results of the deepest boring we are entirely dependent on the diagrams of the bore and the records given in the driller's log. The chief noteworthy features are:—

Depth in Feet.	
40	Salt water.
50	Small show of oil and more water.
80	Black water and oil.
241– 285	Limestones with oil indications.
285– 366	Limestones containing oil. (Specific gravity 0·962; flash point 204° F.)
1,131	Struck salt water which rose over the mouth of the bore.
1,151	Oil and gas flowing between 10-inch and 12-inch casings.*
1,268–1,278	Hot water flowing from bore.
2,024–2,037	Dark limestone with pitch or asphalt.†
2,037–2,062	Dark limestone with oil indications.
2,164–2,204	Hard bituminous limestone.
2,231–2,234	Soft clay with lignite seams.
2,281	Gas.
2,340–2,345	Black sand with water.
2,734–2,775	Red marl with seams of coal.
2,850–2,855	Oil indications in sandstones with some marl.

* The bottom of the 12-inch casing was at a depth of 211 feet. The oil was thus probably from the "limestones containing oil, 285 to 366 feet."

† A sample from a depth of 2,025 feet, tested in the Government Analytical Laboratory, was found to consist mainly of asphaltic matter.

The chief deductions to be drawn from the above notes are: (1) that oil occurred at two distinct horizons, one in the Eocene or uppermost Cretaceous, between 241 feet and 366 feet, and the other in the Cenomanian, below 2,030 feet; (2) that only the upper horizon furnished a *flow* of oil, the lower horizon being characterized by asphaltic matter; (3) that hot water was struck between the two oil horizons; (4) that lignite seams occur in the Cenomanian clays; (5) that coal seams occur in the upper part of the Nubian sandstone series. The flow of oil from the upper horizon stands in close relationship to the similar flow from the neighbouring shallow well to be presently noticed, while the lower horizon containing asphaltic matter can be correlated with but little doubt with certain hydrocarbon-bearing marls discovered in the Cenomanian beds further inland. The hot water encountered between the two oil horizons is suggestive of a fault or fissure being traversed by the bore. As regards the lignite and coal seams, no samples were collected, and it is therefore most likely that their thickness was insignificant, a little coaly matter being found among the pounded-up debris made by the drill; lignitic and coaly matter has been found at about the same horizon (in the Ceno-

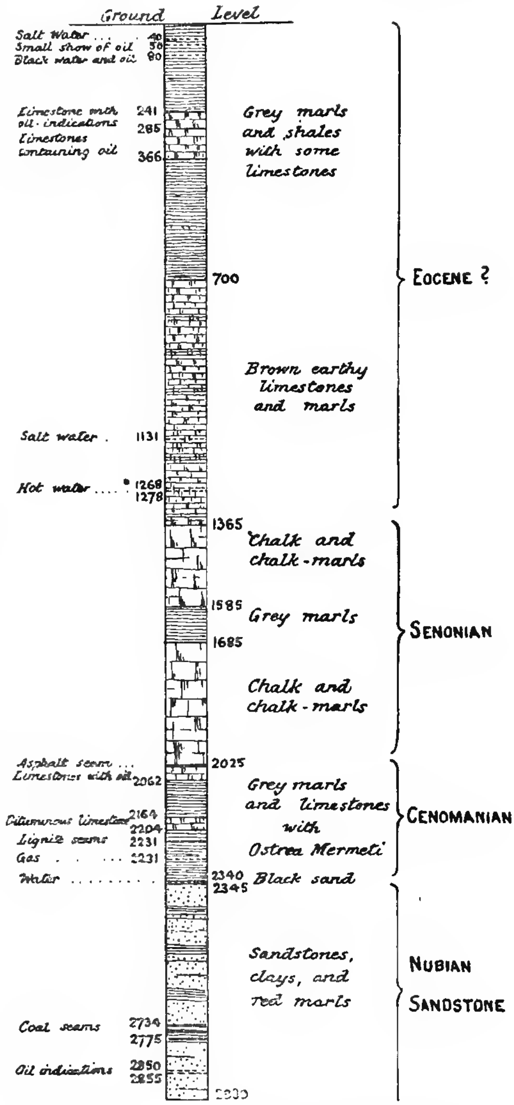

FIG. 54.—Section of boring for oil at Gebel Tanka. The figures show depths in English feet.

manian shales and the underlying Nubian sandstone) further north in Sinai (*see* page 149) and at several places in Egypt,* but no workable seams of fuel. The "oil indications" in the sandstone near the bottom of the well represent the result of the expensive deepening of the bore into the Nubian sandstone; it had been hoped by the driller, not without some reason, that the porous sandstone, with its immense capacity for storing oil, might prove to be a rich reservoir of petroleum which had migrated from neighbouring rocks, but his hopes were doomed to disappointment.

In the shallow well bored to a depth of 510 feet in close proximity to the deep well above described, the strata passed through consisted entirely of shales and limestones similar to the uppermost beds traversed by the deep well. Oil first appeared in the boring at a depth of 378 feet; at 406 feet it was coming into the bore. After the boring was stopped on October 12, 1912, oil continued to rise gradually in the well, and when I visited the place in December 1912 the oil had mounted in the casing practically to ground level.

A sample of the oil from this well, examined in the Government Analytical Laboratory, gave the following results:—

Specific gravity at 60° F.	0·955
Benzine, distilling below 150° C.	0·7 per cent by weight.
Kerosene, distilling at 150–270° C.	11·6 " " "
Fuel oil distilling above 270° C. ...	87·7 " " "

The analyst remarks that the oil has an asphaltic base and contains a trace of vanadium.

In the most southerly well, which was drilled to 2,292 feet, the strata were similar to those of the northern bore, but the oil indications appear to have been less marked, and the boring was not carried down far enough to cut the "coal seams" which were found in the Nubian sandstones in the northern well. At a depth of 130 feet, the driller records "show of gas and black water"; salt water was struck at 1,225 feet; "oil indications" are noted from 2,108 to 2,225 feet. No asphalt seam appears to have been struck in this southern bore. The "show of gas and black water" at 130 feet is probably at about the same horizon as the oil which was reached at about 300 feet in the other two wells, the higher level being in part due to the inclination

* *See* HUME, in the chapter on Egypt in "Coal Resources of the World," Twelfth International Geological Congress, Canada 1913, Vol. II, p. 375.

of the beds; a gradual rise of the strata southwards is quite evident in the adjacent scarp.

It will be remarked that the oil of Gebel Tanka occurs at a much lower level, geologically speaking, than that on the other side of the gulf at Jemsa, the Sinai oil being in Eocene and Cretaceous strata while that of Egypt is found in beds believed to be of Miocene age. Another marked difference between the two sides of the gulf is in the nature of the oil, that of Gebel Tanka having an asphaltic base while the Jemsa petroleum has a paraffin one. We must conclude either that the petroleum deposits on the two sides of the gulf are of different origins, or else that migration and change of composition has taken place in one or other of the two areas.

In seeking for a clue as to the origin of the oil at Gebel Tanka, it is natural to enquire at what places and in what rocks hydrocarbons have been observed to crop out at the surface in the neighbourhood of the wells. A little way back from the sea coast, at various points both to the north and to the south of Gebel Tanka (*see* page 134) hydrocarbons are found in Senonian limestones where these rocks have been intruded by dolerite. The presence of hydrocarbons is accompanied by a blackening of the limestone at these places, and it is observed to extend as a rule only for a few metres from the intrusion. Similar occurrences of hydrocarbons in the immediate neighbourhood of dolerite intrusions are found in the Cenomanian marls in Wadi Watâ, a little way above its junction with Wadi Gharandel (*see* page 142). The presence of these hydrocarbon impregnations in close association with dolerite intrusions is obviously due to distillation and condensation from deeper lying deposits. A similar explanation may be given for the impregnations of petroleum in the Eocene crystalline limestone capping the north end of Gebel Hammam Faraûn, referred to on page 128, except that at this point the volcanic rock has been removed by denudation.

The primary source of the oil at all these places is very possibly to be sought in the Cenomanian marls. As recorded on page 141, thick beds of oil-bearing marls can be traced for some distance in the hills surrounding the upper reaches of the Wadi Abu Qâda. No igneous rocks have been noted in the immediate vicinity of these oil deposits; they have the appearance of being primary deposits, formed in the marls by the decomposition of marine organisms.

Analyses made in the Government Analytical Laboratories of six samples of oil marls from the locality called Etla el Zur (*see* sketch on page 141), gave the following results :—

	A	B	C	D	E	F	Mean of Six Samples.
Water	3·01	3·35	3·00	1·86	3·30	1·66	2·70
Oil soluble in petroleum ether	0·64	1·16	0·56	1·55	0·15	0·99	0·84
Asphaltic material, soluble in CS_2	0·15	0·42	0·36	0·15	0·10	0·22	0·23
Other volatile organic matter	0·25	0·05	0·16	0·10	0·08	0·16	0·13
Total volatile oily and asphaltic matter ...	1·04	1·63	1·08	1·80	0·33	1·37	1·20

Of the above six samples, A, B, and C were taken from the bottom, middle, and top bed respectively of the section shown in Figure 20, page 141 ; D, E, and F from beds at a higher level.

A further two samples collected from similar beds near the Wadi el Nakheila gave on analysis :—

	G	H	Mean of Two Samples.
Water...	2·00	2·79	2·40
Oil soluble in petroleum ether	0·93	1·15	1·04
Asphaltic material soluble in CS_2	0·25	0·12	0·18
Other volatile organic matter	0·22	0·16	0·19
Total volatile oily and asphaltic matter	1·40	1·43	1·41

The Government analyst (Mr. A. Lucas, F.I.C.) accompanied the table of analytical results by the following remarks :—

"The analysis of the marls has been carried out by heating a known quantity and collecting the volatile products formed, which latter were then examined, the water being first removed and then

the oily and asphaltic constitutents dissolved out by means of petroleum ether and carbon disulphide. This separation is necessarily not exact, but it gives a fair indication of the amount of oil and asphalt present. After treatment of the oil and asphalt with the two solvents mentioned, a small residue always remained undissolved, which in the results of the analysis is called 'other organic matter.'

"The residue left in the marl after distilling off the volatile products was darker in colour than the original marl, and contained a certain amount of carbon, thus showing that a little of the hydrocarbons had suffered decomposition during heating. The oil contained, therefore, is not absolutely identical with that occurring in the marl, though the difference is probably quite small.

"Distillation had to be employed to remove the oil, as it was not found possible to extract more that a small portion by the direct action of solvents on the marl.

"No very marked relationships are noticeable among the results obtained, and the nature of the oil in each sample appears to vary, though the amount remains fairly constant."

It appears from the above analytical results that the oil marls at their exposed faces contain on the average about 1·3 per cent of hydrocarbons, of which roughly three-quarters is oil and the remaining quarter is asphalt. The high proportion of asphalt to oil is indicative of inspissation at the exposed faces, and it is not unlikely that the oil content may be larger further in the beds. But even if we reckon on only 1·3 per cent throughout, and an average thickness of a metre for the oil-bearing marl, we have a content of over 25,000 tons per square kilometre. Thus, though the percentage of oil in the marls is far too small for them to be of any economic value as a direct source of oil, it is quite sufficient to provide sufficient quantities at points where natural conditions may have concentrated it.

The layer of asphalt passed through at Gebel Tanka at a depth of 2,025 feet (616 metres) is almost certainly in Cenomanian marls, since specimens of *Ostrea Mermeti* were brought up from a somewhat greater depth. There is thus a strong suggestion that the asphalt layer of Gebel Tanka is the continuation of the oil strata of the Wadi Abu Qâda district, and that the oil found at a shallower depth at Gebel Tanka is a local accumulation produced by distillation from the same beds. If this view is correct, the oil at Gebel Tanka may be expected

to occur mainly along a line parallel to the axis of the Gulf of Suez, this being the general direction of the dislocations and doleritic intrusions which may have conditioned the distillation; it is not likely that the oil will be found to extend to any great distance laterally. As to the prospects of getting oil in quantity by further borings to shallow depths along the coast, all that can be said is that there appears reason to believe that the Cenomanian marls contain quantities of hydrocarbons sufficient to provide a considerable supply of oil, but our present knowledge does not enable us to say whether natural distillation proceeded on a scale large enough to cause accumulations of sufficient magnitude to be worth exploitation.

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